THE ELECTRIC FURNACE

IN

IRON AND STEEL PRODUCTION.

BY

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WITH 24 ILLUSTRATIONS AND A LIST OF PATENTS.

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PREFACE.

IN May, 1906, the Author was invited by the Publishers of the *Iron Trade Review* of Cleveland, U.S.A., to contribute to that paper a series of articles upon the electric furnace methods of iron and steel production.

The articles were written, and they appeared in that Journal during the second half of the year 1906,—they were also published in *The Electrician* (London) at a later date.

In view of the success which has attended certain of the furnaces and processes for refining iron and steel by aid of electric heat, it is thought possible that the collection and publication of these articles in more permanent form may prove a useful contribution to the literature of this new branch of electro-metallurgy.

The present industrial development of these new methods and processes is no doubt small and insignificant when compared with the vast extent and magnitude of the iron and steel industries. The Author has little doubt, however, that it will be upon these new methods that the world will depend more and more for

its supplies of iron and steel, as the coal-fields of Europe and America are gradually exhausted. Electricity generated from water-power will then take the place of coal,—and the electric furnace will supplant the blast furnace and other forms of refining furnace.

The articles are reprinted in this volume in the form and order in which they originally appeared, with slight verbal alterations. An Appendix has been added containing the dates and numbers of the more important English, American and Canadian Patents.

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July 1*st*, 1907.

CONTENTS.

ILLUSTRATIONS.

CHAPTER I.

INTRODUCTION.

In the year 1879 the late Sir William Siemens, of London, patented a crucible form of electric furnace.* In this furnace he was able with comparative ease to melt 10 kg. of iron or steel by aid of the electric current in one hour. Fig. 1 shows the general arrangement and design of this earliest crucible furnace for steel melting.

Basing his estimate of cost upon the results obtained by experiments with this furnace, Sir William Siemens claimed that the electric furnace method of melting steel might be regarded as equal in heating efficiency to a regenerative gas furnace, since in each case the ton of steel required the equivalent of one ton of coal or coke.

But the electric furnace had other advantages in its favour not shared by furnaces using solid or gaseous fuel, chief of these being that the atmosphere of the furnace was uncontaminated with the products of combustion: that practically any degree of heat could be obtained *in the charge* of steel within the furnace: and that this heat could be easily controlled by regulation of the electric current. On these grounds the designer of this earliest form of electric crucible furnace prophesied that electric heating would become of considerable importance in the iron and steel industry of the future.

Twenty years elapsed before any progress could be reported in the direction indicated by the late Sir William Siemens. But in the meantime much important work was carried out by

* No. 2,110. 1879.

the brothers Cowles, Hall, Wilson and Acheson in America; by Héroult and Girod in France; by Borchers and Kiliani in Germany, and by de Lavel in Sweden, bearing upon the practical application of electric heating in the production of aluminium, calcium carbide, carborundum, graphite, ferro-alloys and zinc. Moissan's researches, although confined to the laboratory, must also be mentioned in this connection, for this

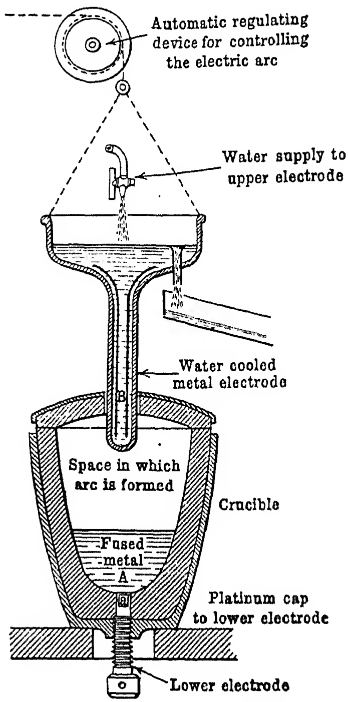


FIG. 1.—SIEMENS' ELECTRIC CRUCIBLE FURNACE.

famous French chemist's work with the electric furnace has become of classical value and importance. In these laboratory and works trials of the electric furnace much valuable information relating to the use of electricity for heating purposes was gained. The best methods of controlling the large currents used, and of arranging the electrodes so as to minimise

their loss and destruction during the heating of the charge in the furnace, were also worked out.

In 1899 Héroult—who had patented and brought into successful operation in Europe the process of aluminium extraction associated with his name about the same time that Hall patented and introduced a similar process in America—turned his attention to the utilisation of the electric furnace for the production of special alloys of iron and steel. A large number of trials were made at the works of the Société Electrométallurgique Française, at Froges and La Praz, in France, with various forms and designs of furnace, the experience gained in the development of the aluminium process being of immense service to Héroult in this work.

Success attended this early experimental work of Héroult, and from the production of ferro alloys in the electric furnace to the manufacture of high class steels was a natural development of his process. Attempts to smelt iron ore directly by aid of electric heat were made about this date, but were not so successful, and Héroult from 1901 to 1905 confined himself chiefly at La Praz to the production of special steels, using scrap and pig iron as the starting point of his process. In this same period Stassano in Italy, Keller, Héroult and Gin in France, and Kjellin in Sweden, were working along the same lines, and each of these electrometallurgists had attained some degree of success in the production of special steels by the new method of heating. In America, Ruthenberg, Conley, Rossi and Wilson were also experimenting with the applications of the electric furnace in the iron and steel industry. Early in 1904 these methods had become of sufficient importance for the Canadian Government to think it worth while to appoint a commission of experts to proceed to Europe to examine their working, and the report of this commission, published at the end of 1904, attracted much attention from metallurgists in all countries.

The Héroult Steel Furnace is being operated at La Praz and Froges in France, at Kortfors in Norway, at Remscheid in Germany, and at Syracuse in the United States, in each case the plant being designed for the industrial production of steel

from pig iron and scrap; while at Sault Sainte Marie, in Canada, experiments have recently been conducted with the Héroult furnace for the smelting of iron ore. These experimental trials were carried out at the expense of the Canadian Government under the personal charge of M. Héroult himself, and the results obtained are stated to have been of considerable promise and value as regards the building up of a new centre of the iron and steel industries at Sault Sainte Marie in Canada.

The Keller furnace and process for steel production are being operated upon an industrial scale at Livet and at Kerrousse in France, and a large firm of French steel makers (Messrs. J. Holzer & Co.) have decided to give the same process a trial at their works—at Unieux (Loire). This plant is to be operated by steam, and will utilise 1,500 H.P. The Keller furnace for smelting ore is in use at Livet, but it is not clear whether it is yet working upon a commercial basis.

The Gin furnace and process are now undergoing trial upon an industrial scale at Plettenburg in Westphalia, Germany, but it must be considered doubtful whether this furnace and process have yet emerged from the experimental stage of their development.

The Stassano process and furnace first received trial at Rome and at Darfo in Northern Italy. These experiments, however, exhausted the funds of the promoting syndicate without any decided success having been obtained. The furnace and process are now receiving further trial at the Royal Arsenal, Turin, under government assistance and control. This process also must be regarded as still experimental in character.

The Kjellin process and furnace have been operated at Gysinge in Sweden since 1901 with considerable success, and arrangements have been made for the operation of this furnace and process in Switzerland, in the United States and in England.

The Conley, Wilson and Rossi methods of iron and steel production are still in the experimental stages of their development, but possibly these and others may develop into

processes of some importance at a later date. The Ruthenberg process appears to have failed, judging from the tenour of some recent reports upon it.

Many thousands of tons of steel and several hundreds of tons of iron have been produced by the more successful and practical of these new electrical furnace processes since the experimental trials were commenced in 1899. This fact, taken in conjunction with the extended scale upon which certain of the processes are now being worked, renders it important that iron and steel manufacturers should devote some attention to this new development of electrometallurgical industry.

CHAPTER II.

THE HÉROULT FURNACE AND PROCESS.

M. Paul Héroult, the French inventor of the process for extracting aluminium from its oxide by electrolysis, was born in Thury Harcourt, Normandy, in 1863, and was educated locally as a mining engineer. He was only 23 years of age when he patented his process for aluminium extraction, and in 1887 he was acting as technical manager of the first erected aluminium works in Europe—at Neuhausen. As stated in Chapter I., M. Héroult turned his attention in 1899 to the production of ferro-chrome, ferro-silicon and ferro-tungsten in a modified form of the electric furnace used for aluminium production, and it was the success of these attempts that suggested to him the use of electric heating in the iron and steel industry. Two distinct furnaces and two distinct methods of work have resulted from these experiments, the one a tilting electric crucible furnace for steel manufacture, the other a modified form of the blast furnace, with electric heating, for pig-iron manufacture. These will now be described in the order named.

1. *The Héroult Electrically-heated Crucible Furnace.*—This furnace is shown in sectional elevation in Figs. 2 and 3. It consists of a closed shallow iron tank thickly lined with a refractory material which will stand the high temperature attained within the furnace without undue softening or corrosion by the slag. This lining consists of dolomite brick, with magnesite brick around the openings. The hearth is formed of crushed dolomite, rammed on top of the dolomite brick lining of the bottom of the furnace. The furnace is

mounted on two curved and cogged bars, which permit of its being tipped sideways and held at any desired angle for discharging purposes. At the opposite side from the discharge lip there is an inlet for the air blast, and also an insulated supporting framework for carrying the two massive solid carbons, 1·70 metres in length, and 360 mm. square, which convey the electric current. These can be moved either in a vertical or horizontal direction by use of the gearing shown in Fig. 3. Openings are provided in the top of the furnace cover for charging, for insertion of the two electrodes, and also for the escape of the gases produced on heating the charge. This latter can be effected either by arc or resistance heating. In the former case, the electrodes are allowed to touch the surface of the slag or metal, and are then raised upwards to the limit of distance which the arc will strike with the current and voltage at command. Two arcs will be formed under these conditions—one as the current enters the charge of slag or metal, and one as it leaves the same—while in between these two points the current will traverse the slag and produce resistance heating.

When resistance heating only is desired the two electrodes are lowered until they dip beneath the surface of the charge, and the current in this case passes from one to the other entirely by the materials forming the same.

The method of producing steel in this furnace is as follows: A charge of steel scrap, pig iron, iron ore and lime—in the requisite proportions and quantities—is placed in the furnace, and this is raised to the melting point by combined arc and resistance heating. The slag formed by the lime and silicates of the ore now rises and floats on the surface of the molten metal, and the further heating of the charge occurs by allowing the electrodes to dip just beneath this slag, but not into the metal beneath it. An air blast is now allowed to enter the furnace at some suitable point, and under these conditions the impurities of the iron and steel scrap become oxidised and enter the slag. By pouring off this slag, therefore, and by renewing the materials which form it once or twice, a very pure product can be obtained. The process is in reality a washing-out

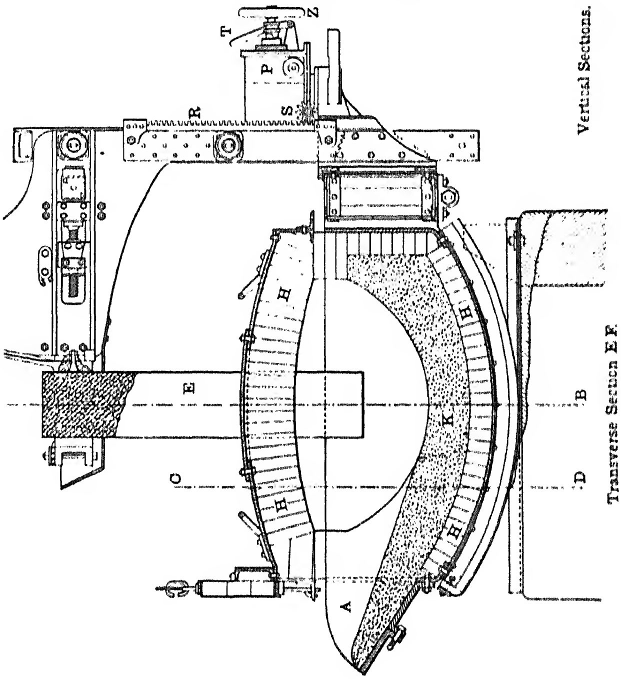


FIG. 2.—TRANSVERSE SECTION OF HÉROULT CRUCIBLE FURNACE.

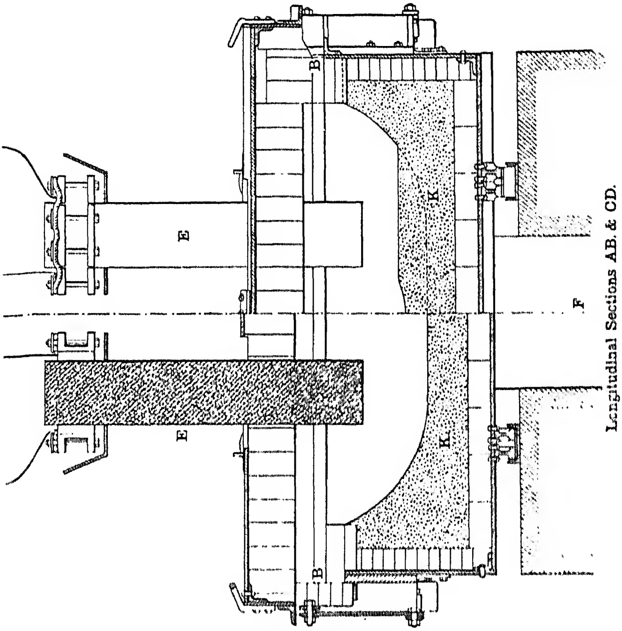


FIG. 3.—LONGITUDINAL SECTION OF HÉROULT CRUCIBLE FURNACE.

process, in which the slag acts as solvent. The fact that all the heating with this type of furnace occurs without any actual contact between the carbon electrodes and the metal also conduces to purity of the products, since no silicon or carbon can enter into the iron or steel from the electrodes. When the iron in the crucible has been raised to the requisite degree of purity by this washing-out process, a calculated amount of an iron alloy high in carbon (carburite) is added, and the resultant steel (of known carbon contents) is tipped into the casting ladle.

A similar method is followed when making ferro-alloys, the requisite weight of alloy, high in the percentage of the metal or element desired, being added to the contents of the crucible just before tipping.

The crucible furnaces usually employed for this process produce 3 tons of finished steel per charge and two charges per day of 20 hours, the current required being 4,000 amperes at 120 volts pressure, or 480 kw. The following test shows the average composition of this steel:—

Iron......	over 99 per cent.	Silicon	0·03 per cent.
Carbon ..	0·60 ,, ,,	Phosphorus	0·003 ,, ,,
Manganese	0·15 ,, ,,	Sulphur ..	0·007 ,, ,,

One of the test runs made by the Canadian Commission of experts at La Praz with the Héroult steel furnace gave the following results:—

The charge was made up of 3,307 lb. of iron scrap, 330 lb. of iron ore, and 246 lb. of lime, being purposely made small to reduce the time requisite for finishing the charge. When the charge had arrived at a tranquil molten state the slag was poured off and every care was taken to remove all of this from the metal left in the crucible. A new slag was now formed by adding the following materials: lime 55 lb., sand 15·5 lb., and fluor spar 15·5 lb. When this slag had been melted it was likewise poured off, and a new charge of slag forming material similar in weight and constitution was placed in the furnace. This formed the finishing slag, and after its removal 1·5 lb. of ferro-manganese was added to the molten mass and the crucible was tipped for discharge. The total time required for finishing the charge was 4½ hours and

2,829 lb. of steel of the following chemical constitution were obtained :—

Carbon	0·079 per cent.	Manganese.	0·230 per cent.
Silicon......	0·034 ,, ,,	Arsenic....	0·096 ,, ,,
Sulphur	0·022 ,, ,,	Copper	traces.
Phosphorus..	0·009 ,, ,,		

The physical properties of this steel were good. The electrical energy required for its production was 1,410 kw. hours, equal to 0·153 E.H.P.-year per ton (2,000 lb.) of finished steel.

A second trial run yielded a steel of high carbon contents testing as follows :—

Carbon......	1·016 per cent.	Manganese	0·150 per cent.
Silicon	0·103 ,, ,,	Arsenic..........	0·06 ,, ,,
Sulphur	0·02 ,, ,,	Copper and Aluminium........	traces.
Phosphorus..	0·009 ,, ,,		

The time required by the charge was eight hours, and the electrical energy consumed was 2,580 kw.-hours, corresponding to 0·153 E.H.P.-year per ton (2,000 lb.) of steel produced. By the use of water-cooled electrodes the consumption of the carbon electrodes per ton of steel has been greatly reduced. The estimated cost of converting iron scrap into steel by the Héroult furnace is £2. 16s. per ton of finished steel. No allowance is made in this estimate, however, for the original cost of the scrap iron, and power is taken at £2 per electrical horse-power-year.

At La Praz eight grades of steel are made, varying from tool-steel of exceptional hardness, selling at £72. 12s. per ton of 2,000 lb., to tough mild steel, selling at £24. 12s. 10d. per ton.

M. Héroult claims for this process of steel making that the quality of the raw material used is a matter of indifference. Steel containing only 0·01 per cent. of sulphur and 0 01 per cent. of phosphorus can be produced from scrap containing 0·15 per cent. sulphur and 0·30 per cent. phosphorus. In his type of electric crucible furnace Héroult claims that he has the temperature of the metal and oxidation of these impurities entirely under control, and he asserts that by this control the desulphurisation and dephosphorisation of the raw materials have been brought to a high degree of certainty and perfection. Héroult also claims that at a cost of 50 cents per ton he can make out of any steel delivered *in the molten state* into his

tipping crucible furnace, a metal containing less than 0·01 per cent. of each of these two dreaded impurities.

As already stated, the Héroult steel-making furnace and process are in operation at La Praz and Froges, in France, at Kortfors, in Sweden, and at Remscheid, in Germany, while the Halcomb Steel Co., of Syracuse, New York, have recently constructed a plant for the production of 80 tons of steel per day by the Héroult furnace and process. Fig. 4 shows the Héroult crucible furnace in operation. The cost of a 2,500 kg. tipping furnace with all the accessories is given by Héroult as

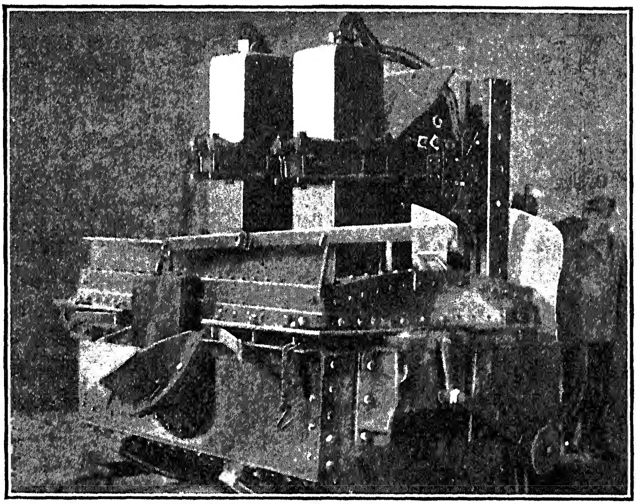


FIG. 4.—THE HÉROULT ELECTRIC CRUCIBLE FURNACE CHARGED.

£2,000, while another £1,000 would be required for the electrode making plant. The electrodes are made from retort coke, using tar as a binding material. The finished electrode costs 1d. per kilogramme at La Praz, with coke at £2 per metric ton.

2. *The Héroult Smelting Furnace and Process.*—The original form of this furnace is shown in sectional elevation in Fig. 5. The principle of the furnace is the continuous supply of the half-fused ore and fluxing materials to a column of coke,

maintained at a red heat by means of an electric current and resistance heating. A, in Fig. 5, is the channel by which the ore and fluxing materials are supplied to the vertical reducing zone of the furnace, while H is the shaft by which the coke is charged. The gases passing away from the hot zone pass up A and thus heat the ore and fluxes before these arrive at the vertical shaft. G, F and B are solid carbon blocks which function as electrodes, the current terminals being placed at I and J. The electric current passing from B to G through the coke maintains this at a red heat, and as the pasty mass of ore and

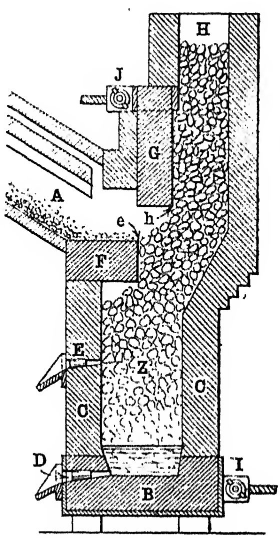


Fig. 5.—The Héroult Electric Ore Smelting Furnace (First Form).

lime passes between the carbon blocks F and G it is likewise heated by the current and rendered more fluid. The liquid charge of ore and lime in its later descent through the hottest zone of the furnace (Z) spreads out, and during its passage through the hot coke, the iron oxide is reduced to metallic iron which collects in the hearth and is run off by the tapping hole D.

This experimental furnace has been somewhat simplified in the light of more extended experience and the smelting furnace

used in the trial runs for the Canadian Commissioners at La Praz, consisted only of an iron box of square cross-section, lined with refractory material and open at the top. The bottom of the casing was provided with a carbon plate, which acted as one electrode of the circuit, the other being a movable block of carbon of square cross-section, 3 ft. in length, and placed vertically in the open top of the furnace. The distance between the electrodes was varied by hand regulation. The charge, consisting of finely divided ore and coke, was placed in the space between the two electrodes, and also around the upper electrode, and fresh ore was added as that in the lower part of the furnace was reduced. The following are the details of the runs made with this furnace:—

3,280 kw.-hours, equal to 0·50 E.H.P.-year. The total output of pig iron was 2,130 lb., and the power used was, therefore, 0·47 E.H.P.-year per ton (2,000 lb.) of pig iron. At £2 per electrical-horse-power-year, the cost of the electrical energy required for the smelting operation was therefore 18s. 10d. per ton of pig iron produced.

In a Paper read in America in 1904, M. Héroult stated that the profitable production of pig iron in the electric furnace was only feasible under certain conditions which did not obtain in most countries, and therefore the practical application of the Héroult smelting furnace and process in Europe has been confined to the production of a few hundred tons of pig iron, chiefly for experimental purposes, at Froges and at La Praz, in France. However, publication of the Canadian Expert Commissioners' report paved the way for a trial of the Héroult smelting furnace in Canada, and a grant having been made by the Canadian Government for the purpose, a small furnace was erected at Sault Sainte Marie, and experimental smelting of Canadian ores was commenced at that place in February, 1906, under the superintendence of M. Héroult himself.

Dr. Haanel, the superintendent of mines in Ottawa, recently read a Paper before the Canadian Club of Toronto, giving some information relating to these trials. Dr. Haanel states that about 55 tons of pig iron were made in 150 runs with

this experimental furnace. The first trials were made with ordinary hematite ore, but, after the furnace had got into good working order, Canadian magnetic ores, high in sulphur contents, from various localities were utilised. Wood charcoal was used in place of coke, which is not produced in Canada. Experiments were also made with roasted and briquetted nickel-iron ores, which are found in large quantities in the neighbourhood of Sault Sainte Marie. These yielded a metal containing 4·5 per cent. of nickel and only 0·006 per cent. of sulphur.

The results on the whole are claimed to have been most promising, since the yield of metal per horse-power was greater than that obtained at La Praz, and the estimated cost of the electrodes was lower than stated in the Commissioners' 1904 Report. M. Héroult estimates that good pig iron can be produced at Sault Sainte Marie at a cost of £2 per ton. The fact that the electric smelting furnace can produce good pig from ores which cost only 5s. per ton, and are unsuitable for use in the ordinary blast furnaces, is also claimed as another point in its favour. The burnt pyrites from sulphuric acid works, and titaniferous ores containing up to 5 per cent. of titanium oxide, are said to be other ores of little value at present which can be utilised in the Héroult electric smelting furnace. Further information relating to these experiments, and to the industrial developments which may be expected to arise from them at Sault Sainte Marie, will therefore be awaited with interest, for it is evident that M. Héroult imagines that he has found, in Canada, the exceptional conditions required for the development of a profitable and flourishing electric iron smelting industry.

The financial aspect of this question, and the writer's own opinions upon the claims made for the Héroult process, will be given in Chapter VII.

CHAPTER III.

THE KELLER FURNACE AND PROCESS.

The French firm of Keller, Leleux & Cie. had been engaged for many years in the production of calcium carbide, ferro-silicon, ferro-chrome and other alloys of iron by aid of the electric furnace, when in 1900 they turned their attention to the manufacture of iron and steel by similar methods of heating. In the experimental trials of various types of furnace for this purpose the surplus electrical power of their large works at Livet Isere was used, a total of 15,000 H.P. (water power) being available at this place. The firm have other works at Kerrousse (Morbihan), where water power to the extent of 600 H.P. is developed. The output of ferro-alloys by these two works in 1904 included 3,000 tons of ferro-silicon, 1,800 tons of silico-spiegel, 960 tons of ferro-chrome and considerable amounts of ferro-manganese.

The experiments with electric furnace methods of iron and steel production were at first carried out at Kerrousse, but as the size of the furnace used and current required for these were increased, the experiments were ultimately transferred to the larger works at Livet, and it was here that the Canadian expert Commission witnessed the Keller furnace and process in operation in March, 1904. In the following description of the furnaces and process devised by Keller for iron and steel production the report of the Canadian Commissioners has been largely drawn upon. This has been supplemented, however, by information obtained by personal correspondence with the inventor, M. Keller, and by facts taken from recent issues of the English, French and German technical journals.

I. *The Keller Iron-Smelting Furnace.*—Keller's first patents for an electrically-heated iron-smelting furnace are dated 1900. Fig. 6 shows the general arrangement of this earliest furnace, which in appearance and design resembled the ordinary blast furnace. The iron ore was charged into the vertical bell-shaped shaft A, with the requisite amount of coke and lime, and the materials were heated in their slow progress down-

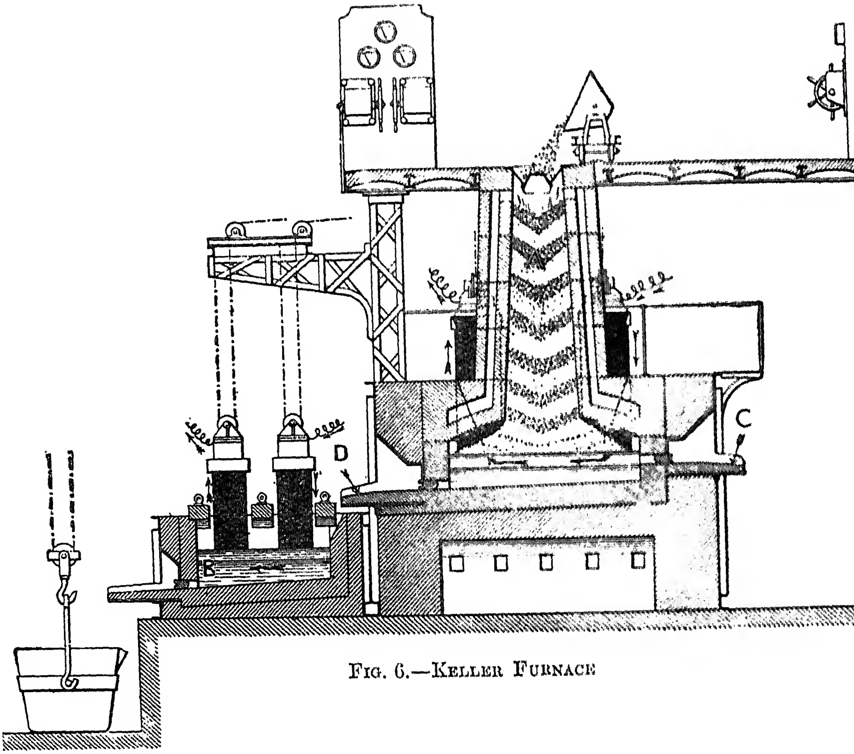


FIG. 6.—KELLER FURNACE

wards by currents passing from the electrodes shown on either side of the column. The ore was reduced to metallic iron in its descent, and on reaching the hearth of the furnace in the molten state the slag passed off at C, while the molten iron was run by D into B, where it was further refined by electric heat before casting into pig.

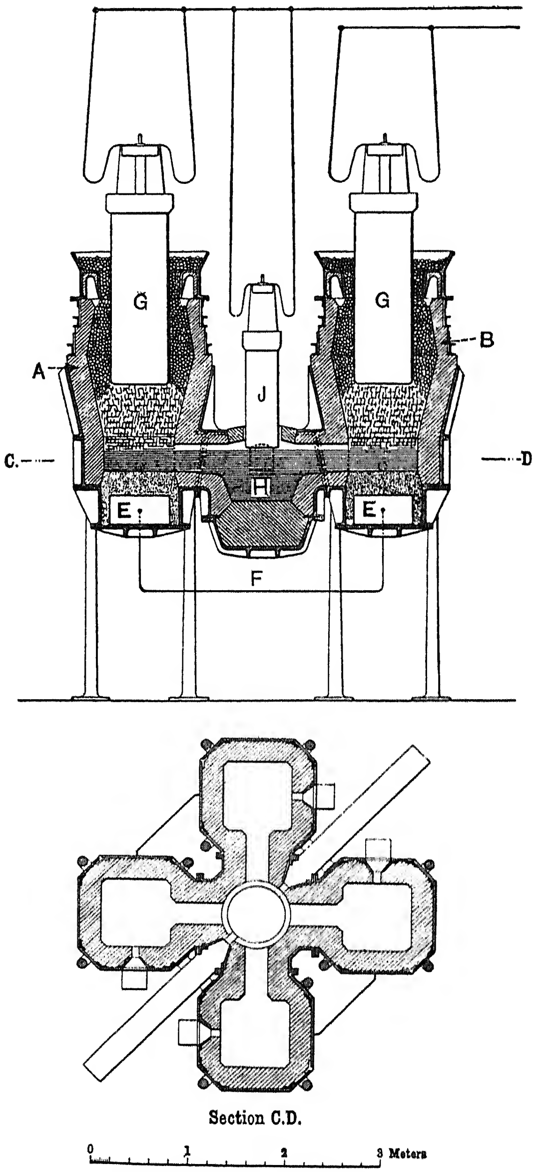


FIG. 7.—KELLER'S SECOND FORM OF FURNACE.

As this type of furnace has been displaced by one which is described below, it is not necessary to enter into further details concerning it; but it may be stated that a 375 H.P. furnace of this earlier type was erected and worked for some time at Kerrousse, and that it was estimated that 1 ton of steel could be produced in it with the expenditure of 2,800 B.T.U. of electric energy and at a total cost of £4.

The second form of furnace which has been designed by Keller for smelting iron ore is shown in Fig. 7, this being the form used by the Canadian Commissioners in their trials of the Keller process at Livet. The furnace is of the resistance type, and consists of two iron-cased shafts, A and B, communicating below by a horizontal canal, C. The shafts are lined with refractory material, and each is provided with a massive carbon block electrode, G, slung on chains, and movable in either a horizontal or vertical direction. The base of each shaft is also provided with a carbon block electrode E, electrically connected by thick copper bars F passing outside the horizontal canal. The vertical electrodes hang for two-thirds of their length within the shaft. The refractory material used by Keller for lining the shafts and lateral canal consists of burnt dolomite (magnesia) and tar. In starting the furnace the charge is introduced between the carbon blocks of the base, and the ends of the electrodes. The current passes from one electrode through the material to be reduced, to the carbon electrode in the base of the furnace. From this it passes to the other base electrode by the external copper conductor, and through the charge in the second shaft in the reverse direction to that just described. When the electric resistance heating has caused portions of the charge to be reduced to the molten state and metallic iron to be formed, this collects on the hearth of each shaft and finally flows into the lateral canal CD, as shown in Fig. 7. The electric current will now pass from A to B partly by the external conductor and partly by the molten metal in the lateral canal, and as this fills up, the proportion of the total current carried by the external conductor diminishes. The electrodes are gradually raised as the charge in the shafts is reduced and melts, and fresh raw materials are charged into

the vertical shaft. The external conductor between the two base electrodes enables the furnace to be worked continuously. Any temporary block or stoppage in the lateral canal due to cooling is overcome by the use of a supplementary electrode as shown in Fig. 7 at J.

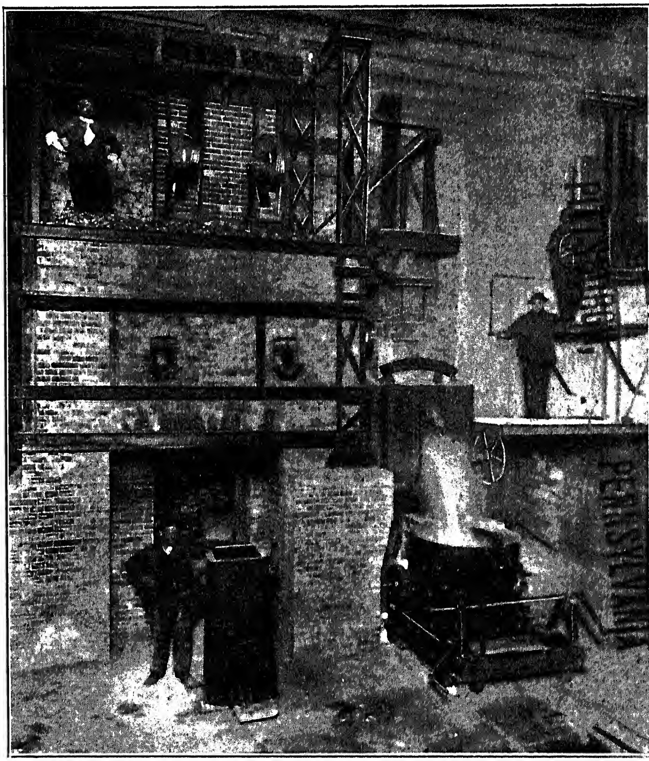


FIG. 8.—KELLER FURNACE DISCHARGING.

The vertical electrodes of this furnace are each formed of four carbons of square cross-sections, the composite electrode thus produced being 850 mm. (34 in.) square, and 1·4 metres (56 in.) in length. The amount of electrode carbon consumed per charge is small, owing to the low E.M.F. employed in working the furnace. In 15 days two electrodes had only lost

400 mm. (16 in.) of their original length, and M. Keller estimates that the electrodes in these furnaces will last 20 days before requiring renewal.

The cost of their manufacture is estimated on these figures to be 3·85 fr. (3s.) per ton of iron produced.

Two sets of experiments were carried out by the Commissioners with this furnace, grey, white and mottled pig iron being produced, and the influence of carbon added to the charge of ore upon the consumption of electrical energy being determined. The use of charcoal in place of coke was also tried, but this experiment failed.

The ore used in these trials of the Keller furnace was only roughly crushed and mixed with the coke and lime, the jaws of the crusher being set to 2 in. In the first run of the furnace 15,943 kg. of ore were charged, and 9,868 kg. of pig iron were produced in 55 hours, while in the second run, lasting 48 hours, 13,310 kg. of ore were used and 6,692 kg. of pig iron were produced.

The energy used per ton of pig iron produced in these trials was 0·475 E.H.P. year and 0·226 E.H.P. year respectively, the lower figure being obtained with the smaller furnace of 308 H.P. capacity.

Basing their estimate of cost on the mean of these two figures (0·350 E.H.P. year) the Commissioners calculated that pig iron could be produced in the Keller furnace at a total cost (exclusive of royalty) of £2. 8s. 3d. per ton.

Since these trials by the Canadian Commissioners at Livet M. Keller has continued his experiments with the 1,000 H.P. furnace, and has satisfied himself that the electro-thermic process gives him complete control of the silicon and carbon contents of the pig iron produced, and that the metal produced is equal to that obtained in the blast furnace from the same ore. It is also claimed for the electro-thermal method of production in the Keller furnace that the percentage of silicon and carbon can be varied at will.

A 2,000 H.P. furnace for production of 20 tons of grey iron castings per 24 hours has since been erected at Livet, the furnace being constructed on the four-hearth type. In this type

of furnace (see Fig. 9) four shafts connect with a central canal, and the tapping of the slag and metal occurs from this central

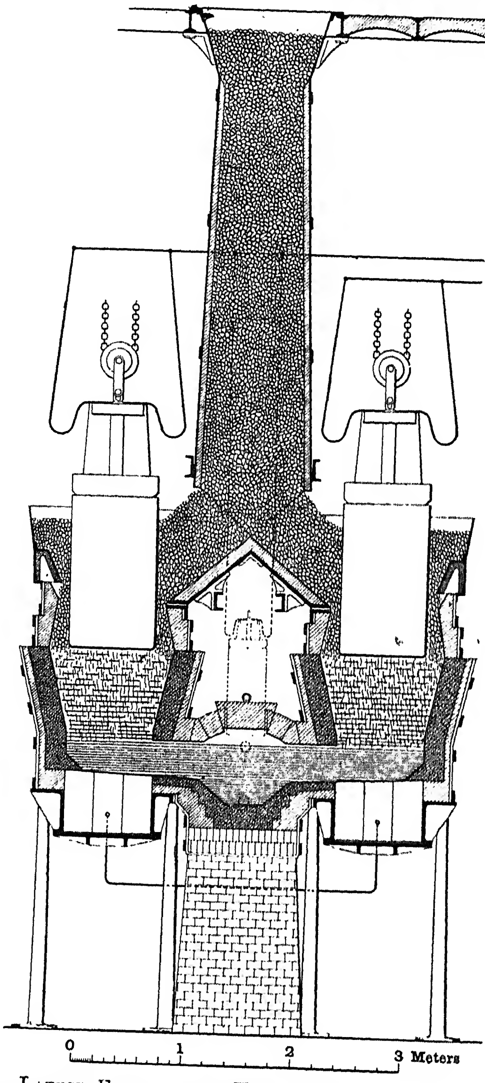


FIG 9.—LATEST FORM OF THE KELLER ELECTRIC HIGH FURNACE WITH A PLURALITY OF HEARTHS.

chamber while the escaping gases are also employed to heat the descending charge. Fig. 10 shows a still larger scheme for a Keller furnace plant producing 100 tons of pig iron per 24 hours; but this project is on paper only, and has not been worked out upon a practical scale. A water power producing 12,000 H.P. would be required to provide the necessary electric current for this scheme, and five four hearth furnaces would be installed.

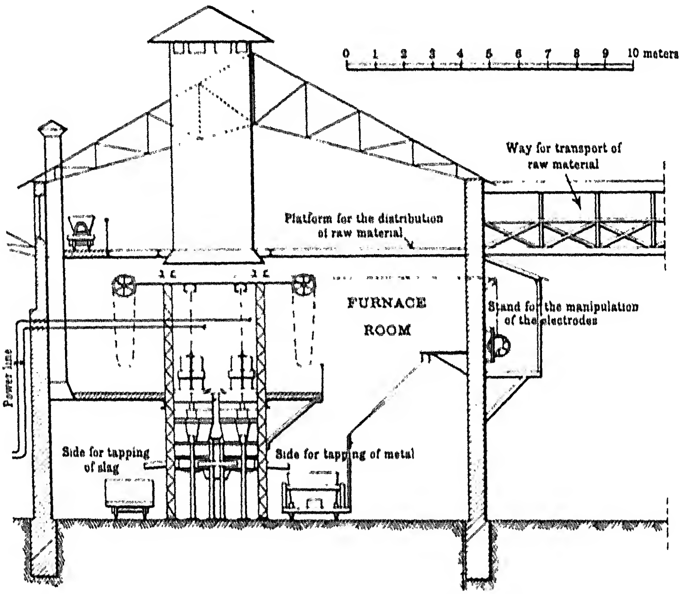


FIG. 10.—PROPOSED ARRANGEMENT OF KELLER FURNACE FOR PRODUCING 100 TONS OF PIG IRON IN 24 HOURS.

Although many hundreds of tons of iron have been produced at Kerrousse and at Livet, the Keller iron-ore reduction furnace has not been adopted by any outside firm so far as the writer is aware, and for this reason it must still be considered in the experimental stage of its development. M. Keller himself recognises that, if adopted, it will be in countries possessing iron ores but lack of coal with which to smelt them, Chili, Brazil and New Zealand being named in this respect.

II. *The Keller Steel Refining Furnace.*—The Keller steel-refining furnace is shown in sectional elevation at B, see Fig. 6. In the later designs of the Keller iron-producing plant the refining furnace has not undergone much modification. As shown in Fig. 6 it consists of a fixed chamber lined with refractory basic material and heated by two massive carbon electrodes suspended vertically above the metal in the furnace. In principle and design this refining furnace has little to distinguish it from the Héroult refining furnace. In the Keller furnace, however, the electrodes are not allowed to dip beneath the slag, but only to touch the same. This method of leading the current into and away from the molten slag and metal beneath it involves the use of a higher E.M.F., and, therefore, of a larger expenditure of electrical energy per ton of metal refined; but as compensation for this it is claimed there is less danger of the produced steel being contaminated with the impurities of the electrodes, while the consumption of the carbons is reduced, owing to these being little exposed to the oxidising properties of the slag.

In later modifications this furnace is provided with tilting mechanism, and the slag is poured off, exactly as in the Héroult type of refining furnace. A further resemblance to the Héroult procedure is the use of the slag for washing out the impurities of the iron, and in the addition of two or more charges of slagging material before the refining operation is completed.

A trial run with this furnace was made at Livet by the Canadian Commissioners, but owing to lack of time only one slag was poured off, and the run was stopped before the refining operation was completed. No conclusions could therefore be based upon the results obtained, but the furnace in principle and operation is so similar to that of Héroult that separate trials of it were practically unnecessary.

Although the Keller plant at Livet has been used chiefly for the production of pig iron and castings, and not to any great extent for that of steel, a Keller electric furnace refining plant has been installed at the works of Messrs. Holtzer & Co., Unieux, France. This refining furnace weighs about 50 tons,

rests on a steel cradle, and can be tilted for discharging purposes. A 1,500 H.P. steam driven generating set will supply the necessary electric energy, and the iron to be refined in this furnace will be run into it, in the molten condition, from a Siemens-Martin furnace.

A current of 20,000 amperes at 60 volts will be employed, and it is expected that an output of three or four charges of 8 tons each per day of 24 hours will be obtained.

This is the first trial of the electric steel-refining furnace in an up-to-date steel works in France, and the future of electric refining will depend very largely upon the success or otherwise of the installation at Unieux.

The use of molten iron from the Siemens-Martin furnaces as charging material for the electric refining furnace is a step that was advised by the writer some years ago, and it is surprising that its practical application has been so long delayed. The electric furnace will most probably first be adopted as an accessory appliance in the modern iron and steel works, and there is little doubt in the writer's mind that the trial at Unieux will be followed by similar installations in other works where high-class steel for tools and motor-car work is produced.

CHAPTER IV.

THE KJELLIN FURNACE AND PROCESS.

This furnace and process are the invention of Mr. F. A. Kjellin, a Swedish engineer, whose first patent was dated August 1, 1900. The process differs from other electric iron and steel processes in the use of induced currents for heating the iron. By this means the waste of heat occurring in the Heroult and Keller furnaces and processes, due to the unnecessarily high temperature of the electric arc, is avoided, while the expense and disadvantages attending the use of carbon electrodes are also overcome, since in the Kjellin furnace no electrodes are required.

On the other hand, the Kjellin furnace is not adapted for dealing with impure materials, owing to the comparatively low temperature obtained, and the elimination of phosphorus, sulphur and other objectionable elements present in iron ores and in scrap iron cannot be carried out so completely as in the Héroult and Keller furnaces. Electrical difficulties due to self-induction also reduce the efficiency of the Kjellin furnace and process, and its superiority to the processes making use of combined arc and resistance heating with carbon electrodes is less striking than might be expected, the chief gain being in the purity of the product, which resembles ordinary crucible steel.

However, furnaces of constantly increasing size, operated upon the Kjellin principle of using the molten iron as the resistance for induced currents of electricity, have been erected and worked at Gysinge in Sweden since 1900, and similar furnaces are now in course of erection in many countries. The

fact that Messrs. Siemens & Halske, of Berlin, have purchased the patent rights of the furnace and process for Germany and Austria, and that Messrs. Krupp are now erecting a Kjellin furnace plant for production of crucible steel at Essen, also proves that the Kjellin furnace and process is one that has achieved a permanent position in the iron and steel industry.

Fig. 11 shows a sectional elevation and plan of the furnace erected there in 1901-1902. The furnace practically consists of a transformer of which the core is CC; the primary is the coil DD, which is supplied with alternating current, and the secondary is the molten metal in the annular channel AA. The current in the metal is roughly that in the primary multiplied by the number of turns in the coil.

The first runs with the experimental furnace were made at Gysinge in March, 1900, 270 kg. of steel of excellent quality being produced in 24 hours with a power input of 78 kw. This was equal to 6,912 kw. hours per metric ton of steel. In order to improve the efficiency of the process a larger furnace was erected, and in November of the same year, trial runs with this furnace yielded 600-700 kg. of steel per 24 hours with an expenditure of 58 kw., equivalent to 2,141 kw.-hours per metric ton of steel. This was an improvement, but the inventor was convinced that, with a larger furnace, still better results could be achieved. In August, 1901, the sulphite wood-pulp mill at Gysinge was destroyed by fire, and the owners decided to devote the whole of the water power at this place to steel manufacture, in place of erecting a new wood-pulp mill. A larger Kjellin type of furnace, capable of containing 1,800 kg. of steel, was erected, and this commenced work in May, 1902. This furnace produces 4,100 kg. of steel ingots per 24 hours, with an expenditure of 165 kw., and a current approaching 30,000 amperes in the secondary circuit. The energy consumption is therefore 965 kw.-hours per metric ton of steel. Only 800 kg. to 1,000 kg. of metal are poured at each casting, the remainder being left in to act as conductor for the current and to avoid stopping the turbine or alternator. To this molten metal left in the furnace, the proper quantity of pig iron and steel scrap are added to form the new charge, the proportion

being calculated to yield steel of the desired composition. There is always less carbon in the finished steel than is contained in the charged material, but rather more silicon, owing to the fact that the rust or oxide of iron in the pig and scrap is reduced to metallic iron, and that the silicic acid of the furnace lining is also reduced by the carbon present in the charge.

The tapping of the furnace was originally effected by making a hole in the wall, but a tilting furnace has since been constructed, and the casting charge is now poured. The charging of the raw material is done from the working floor above the furnace, the covers shown in Fig. 11 at BB being taken off, and the pig iron and scrap steel being placed in the annular ring.

The furnace described above has been in operation at Gysinge since May 1902, and in February 1903 it was visited by the Canadian experts and seen by them in operation. An alternating current of 90 amperes at 3,000 volts was supplied to the primary circuit of the furnace, this being transformed in the charge of molten metal contained in the annular ring to a current of 3,000 amperes at 7 volts.

The air space DD, in Fig. 11, was found to keep down the temperature of the primary coil; and in addition to the cooling produced by this draft of air, water could also be employed for this purpose. The loss of heat by radiation, &c., when the temperature of the furnace is 1,400°C., was estimated by the inventor to equal 80 kw., and the efficiency of the furnace was calculated by him to be 45·5 per cent. The temperature of the steel when tapped was 1,600°C. to 1,700°C.

It may be remarked that the figures given on pp. 2 and 3 of the Canadian Commissioners' Report do not agree with these calculations, since the discrepancy between the energy in the primary and secondary circuits of the furnace amounts to $270 - 21 = 249$ kw. Assuming that the current in the secondary circuit was 30,000 amperes and not 3,000 amperes, as stated in the report, the losses between the two circuits are $270 - 210 = 60$ kw.

Three runs were made with the furnace in the presence of the Commissioners at Gysinge on Feb. 8 and 9, 1904, and the following figures were obtained :—

Charge No. 546..Time, 6 hrs...Ingots, 1,030 kgs...Total k.w. hrs., 857.
Charge No. 547.. ,, $6\frac{3}{4}$ hrs... ,, 955 kgs... ,, 994.

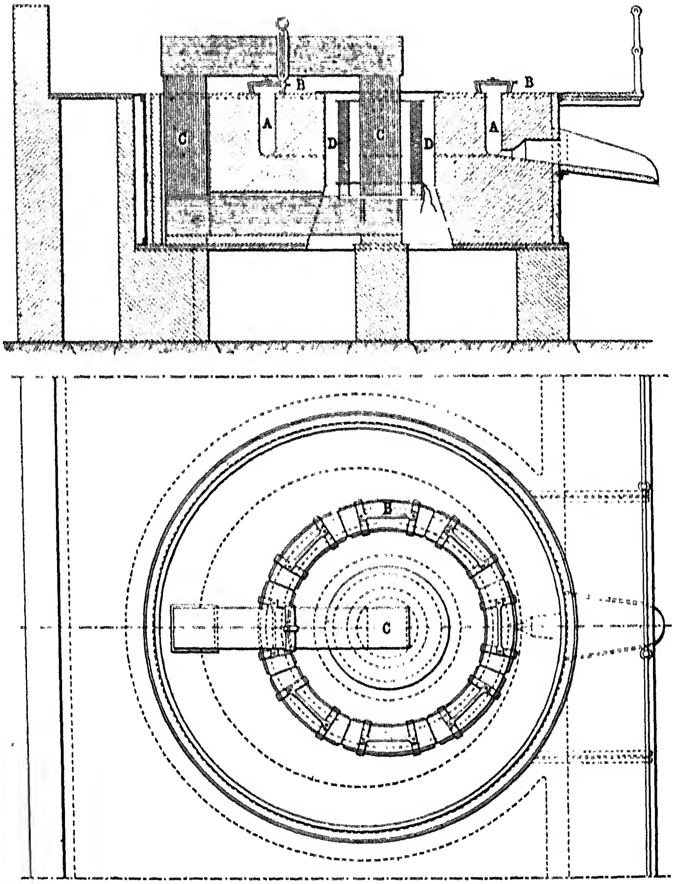


FIG. 11.—SECTIONAL ELEVATION AND PLAN OF KJELLIN FURNACE.

The consumption of energy in the first case was, therefore 832 kw.-hours per metric ton of ingots, and in the second case 1,040 kw.-hours.

The steel produced in these runs were found to have the following composition:—

	Charge No. 546.		Charge No. 547.
Carbon	1·082 per cent.	......	0·417 per cent.
Silicon	0·194 ,,	......	0·145 ,,
Sulphur	0·008 ,,	......	0·008 ,,
Phosphorus	0 010 ,,	......	0·010 ,,

The raw materials in each case were best Swedish pig iron and Walloon bar iron, with scrap steel from previous charges, the proportion of these being varied according to the type of steel required for casting.

Attempts to produce a low carbon soft steel were made by the Canadian Commissioners, but owing to unexpected difficulties were not successful.

The cost of producing steel by this process was estimated by Mr. Harbord to be £7 per ton of 2,000 lb., with electric energy at £2 per electrical horse-power year.

The cost of erecting a furnace of the Kjellin type of 600 H.P. capacity was stated to be about £830.

The Swedish patents for the Kjellin furnace and process are owned by the Metallurgiske Patent Aktiebolaget, of Stockholm, and licences have been granted by this company to the new owners of the Gysinge Works, to a prominent English steel works, to a French firm at Voiron, and to a Swiss Calcium Carbide Company with works at Gurtnellan. A small experimental furnace erected at the latter place has worked satisfactorily, and it is now intended to erect larger furnaces and plant. The patent rights of the Kjellin furnace for Germany and Austria have been sold to Messrs. Siemens & Halske, and Messrs. Krupp have arranged to erect and work a furnace of this type, under licence from the Berlin firm.

A project is also under discussion in Stockholm for the development of the Trälhatta Waterfall, in the province of Norrland, where extensive deposits of iron ore are found, and for the use of the electric energy for creation of an iron and steel industry with the aid of the Kjellin furnace and process. The project covers the transmission of the power from the Falls to a point near Gothenburg, where a steel works producing 500,000 tons per annum will be erected by the Stockholm

company owning the Kjellin patents. The Swedish Government is reported to have given its sanction to this scheme, and to have agreed to develop the Trälhatta Waterfall. It is expected that 10,000 to 15,000 H.P. will be available for this new iron and steel centre early in the year 1908.

An experimental Kjellin furnace has also been installed in the metallurgical department of the University of Sheffield, the home of the English steel industry.

CHAPTER V.

THE STASSANO FURNACE AND PROCESS.

The Stassano furnace and process for smelting iron ore by the aid of electrically-generated heat is the oldest of those described in these chapters, the first patent having been granted to Stassano, who was then a captain in the Italian Artillery, in April, 1898.

The early experiments were made at Rome in the year 1899, and, the results of these having been looked upon as promising, a company was formed to exploit the furnace and process upon an industrial scale of operations, a plant capable of utilising 1,500 H.P. being planned for erection at Darfo in Northern Italy. This plant was partially completed, and the Stassano furnace was seen in operation there in 1901 by Dr. Hans Goldschmidt of Essen, who prepared an official report upon it for the German Patent Office. The company controlling this development unfortunately exhausted its financial resources before the furnace or process had become a success from a commercial point of view, and the operations at Darfo ceased in the following year. The Italian Government, however, arranged with the inventor to carry on the experimental work with the process at the Royal Arsenal, Turin, and the Canadian Commissioners inspected the furnace at this place in March, 1904. The refractory roof of the furnace had fallen in some time before their visit, and, as there had been some delay in obtaining the materials for its repair, the Commissioners were not able themselves to witness the furnace in operation.

The experiments with the Stassano furnace are, however, being continued by the Forni Termoelettrici Stassano at Turin, and according to the most recent information kindly given by

Major Stassano to the author, a plant of four furnaces capable of utilising 2,300 H.P. is now under construction at this place. The plant is to include two furnaces of 1,000 H.P. each, and two smaller furnaces of 200 H.P. and 100 H.P. respectively, one of the larger and one of the smaller furnaces being of the rotating type. At the date of Major Stassano's letter (July 11, 1906) only the two smaller furnaces had been completed and were in regular operation.

The Stassano furnace is not, to the author's knowledge, in operation in any other place than Turin, and on this account the furnace and process must be regarded as still in the

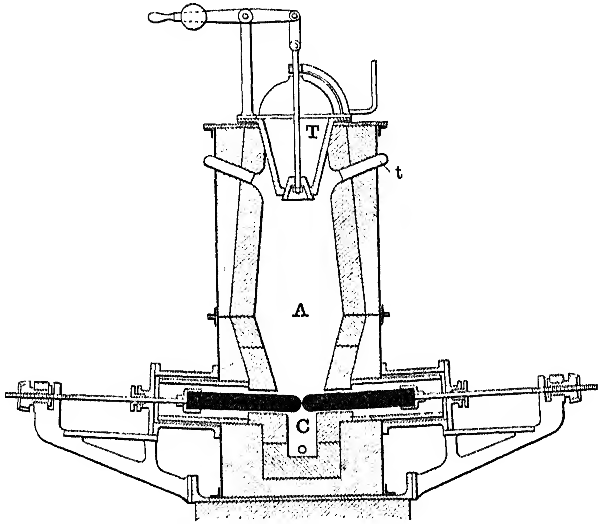


FIG. 12.—THE STASSANO FURNACE. Earliest form.

earliest stage of their industrial development. As the oldest of the electric furnace methods of iron and steel production and one possessing some peculiar features in design, the Stassano furnace and process are, however, worth some attention and study by electro-metallurgists, more especially as very pure iron and steel can be produced by it.

Fig. 12 shows the earliest form of furnace designed by Stassano, this being what is called by the inventor the fixed

type, in contrast with the rotating type which he designed and patented later. This figure shows a furnace constructed on the blast furnace principle, with two solid carbon electrodes in the throat of the furnace above the hearth. The ore, coke, and fluxing materials were charged into the hopper T, and these were heated, as they travelled downwards, by the hot gases rising from the lower part of the shaft and passing away at *t*. The actual reduction of the ore occurred in the neighbourhood of the electric arc at C. This furnace was tried at Rome and Darfo, but it was soon discarded for the rotary form of crucible furnace shown in Fig. 13. This furnace was of the arc type, and consisted of an outer cylindrical casing of iron lined with magnesite and surmounted by a dome-shaped roof. The raw materials were charged into this furnace by the hopper at D, being first ground and then mixed and formed into briquettes; the heating occurred by radiation from the arc between the two carbons at BB^1, and the electric connections were arranged for by an annular ring and brushes. The carbon holders were water jacketed, and their movement was controlled by hydraulic power. The molten metal was discharged at E, and the slag at F.

This furnace could be rotated about its axis, with a movement of 7 deg. from the vertical, and the charge of ore or scrap upon the hearth was thus subjected to a mixing movement during the melting and refining process. Stassano claimed for this form that it satisfied all the requirements of a perfect iron or steel electric melting furnace—these being in his opinion as follows:—

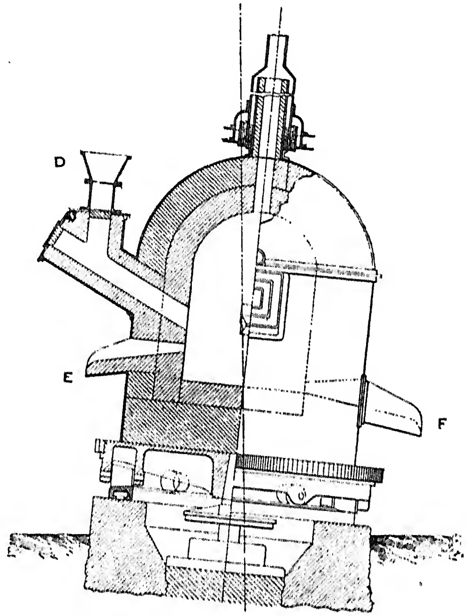
1. The exclusion of air and presence of a neutral or inert gas in the melting chamber.

2. A very high temperature.

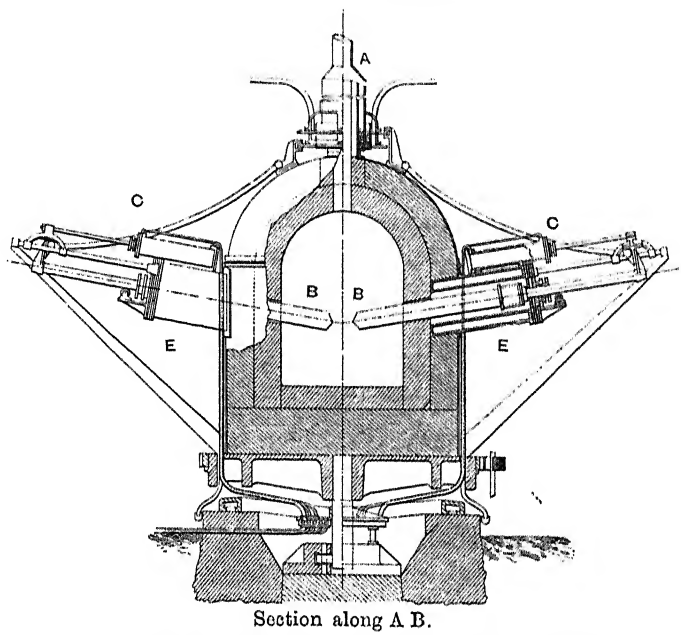
3. No contact of the raw materials or molten iron and steel with the carbons or electrodes.

4. Machinery always under full load when in operation.

This was the form of furnace used by Dr. Goldschmidt in his experimental trials with the process at Darfo in 1901, and from these trials the following figures were obtained.



Section along C D.

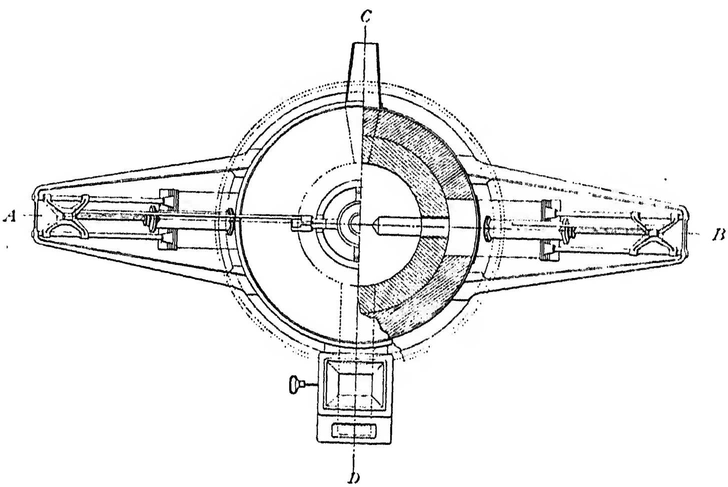


Section along A B.

FIG. 13.—STASSANO ROTARY FURNACE WITH TWO CARBONS.

The furnace was rated at 80 kw. capacity, and normally absorbed 1,000 amperes at 80 volts. The charge of 70·25 kgs. consisted of ore, coke and limestone in the following proportions: Iron ore 1,000, limestone 125, carbon 160, additions 120.

The reduction of the charge was completed in two hours, the electric current being gradually increased to a maximum of 1,000 amperes at 100 volts, and then correspondingly reduced and increased again, towards the end of the operation. The power consumed was 97,200 watt-hours, or 132·24 E.H.P.-hours, and the product obtained weighed 30·8 kgs. This



Sectional Plan.

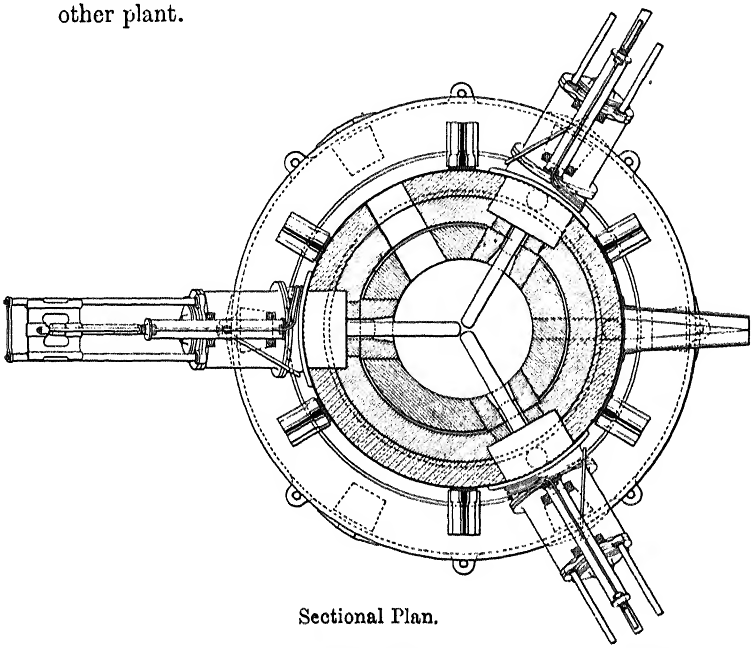
Fig. 13.—Stassano Rotary Furnace with Two Carbons.

was equivalent to 4·3 E.H.P.-hours per kilogramme of iron, and Goldschmidt calculated that it represented a furnace efficiency of 61 per cent. The iron and steel produced in these experimental trials of the Stassano furnace at Darfo was exceptionally pure, the percentage of carbon being reduced as low as 0·04, and only traces of silicon being found in some of the finished metal. Goldschmidt estimated, as a result of his study of the process, that one metric ton (1,000 kg.) of steel could be made in a plant producing 30 tons of steel per 24

hours by the Stassano method, at a cost of 75.20m., equal to £3. 15s. per ton.

The power in this estimate was taken at the low cost of £1. 16s. 6d. per electrical horse-power year.

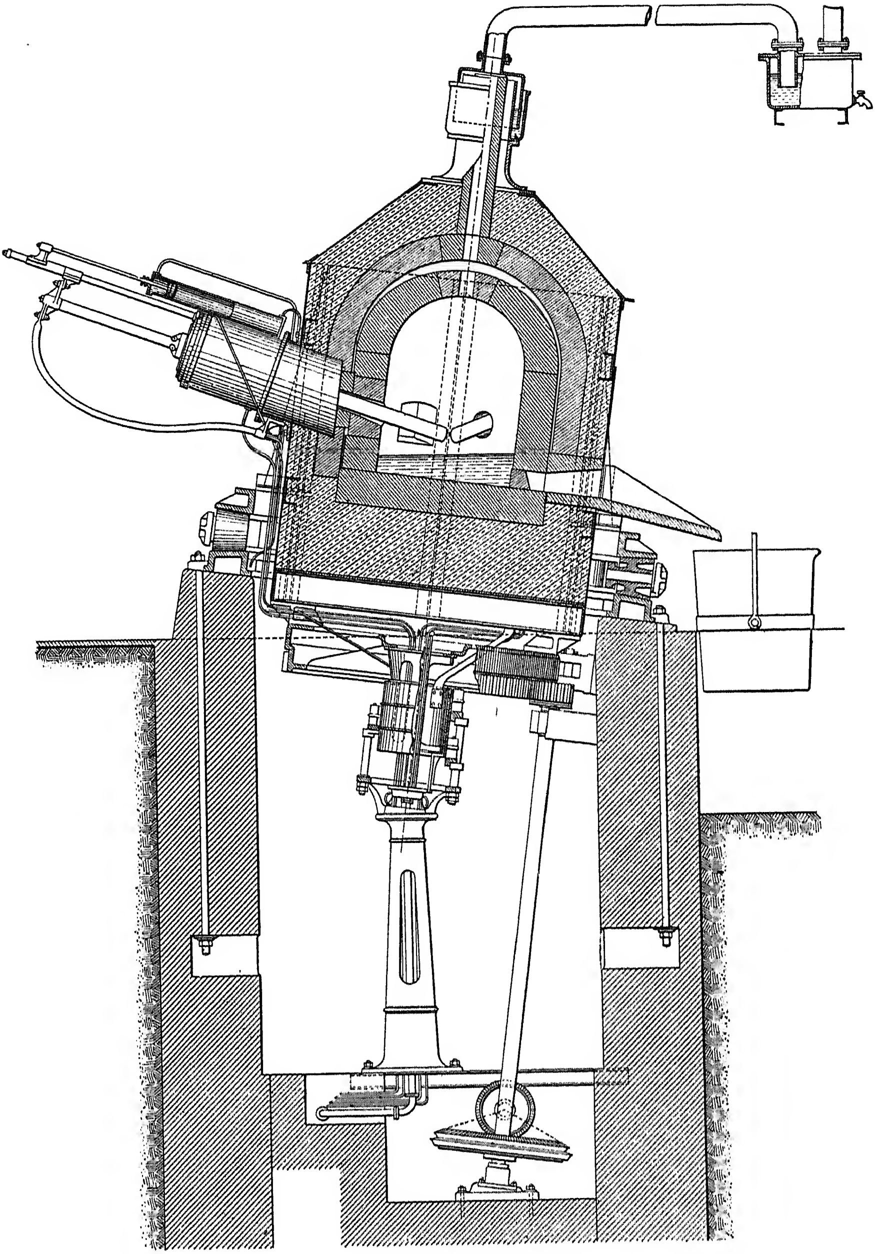
Although Goldschmidt's report was favourable to the continued operation of the Stassano plant at Darfo, the works was not a success, and the company financing this venture was obliged to go into liquidation and to sell the furnaces and other plant.



Sectional Plan.

FIG. 14.—STASSANO ROTARY FURNACE FOR THREE-PHASE WORKING.

The modified form of rotating furnace which was erected by Major Stassano for the Italian War Office at Turin, seems to have been more successful. This furnace is shown in Fig. 14. The furnace has three carbon electrodes in place of two, the distance of these apart and length of the arcs being regulated as before by hydraulic cylinders actuated by water pressure. A three-phase current of 400 amperes at 90 volts is used to work the furnace. Either iron or steel can be made in this



Sectional Elevation.

Fig. 14.—Stassano Rotary Furnace for Three-phase Working.

furnace as desired, the raw materials being chosen and their amount calculated according to the product desired. At Turin the furnace is used for making mild steel for shot (*i.e.*, for shell) from iron and steel scrap. In a letter dated April 12, 1906, the Director of the Royal Arsenal states that, after two years' experience, they are perfectly satisfied with the application of the furnace to this purpose.

According to the same authority, the furnace has a capacity of 2,500 kg. of steel per 24 hours and consumes for each charge of 625 kg. of steel, 850 kw-hours of electric energy in the form of three-phase current at a pressure of 80 volts between the phases. The energy consumption is, therefore, 1·36 kw.-hours per kilogramme of steel, equivalent to 1·85 E.H.P.-hours, a distinct improvement upon the Darfo results. Stassano has, however, pointed out that the power consumption is much lower when melting scrap than when reducing iron to the metallic state from its ores, and has explained the cause of this difference.

The inventor gives the following estimate for the 1,000 H.P. furnace of this type, which has been erected at Turin by the Forni Termoelettrici Stassano :—

Cost of furnace, 25,000 fr.
Output per day, 4 to 5 tons.
Current, 4·900 amperes at 150 volts.
Electrodes, four in number, each 1·50 metres in length and 15 cm. in diameter. Consumption of electrodes, 10 kg. to 15 kg. per ton of steel.
Arcs, two arcs, each taking 2,450 amperes.
Lining, magnesite brick.

Major Stassano believes that the use of four electrodes will lead to notable economy in production, since it will be possible to use one or two arcs, according to the amount of heat required at the various stages of the reduction process. In order, however, to keep the electrical machinery at full load—an essential condition of economical work—it will be necessary to operate two of these furnaces in combination, and to arrange that one shall be taking the maximum current when the other furnace is taking its minimum requirement of electrical energy.

In order to still further reduce the energy consumption per ton of finished iron and steel, Stassano is now experi-

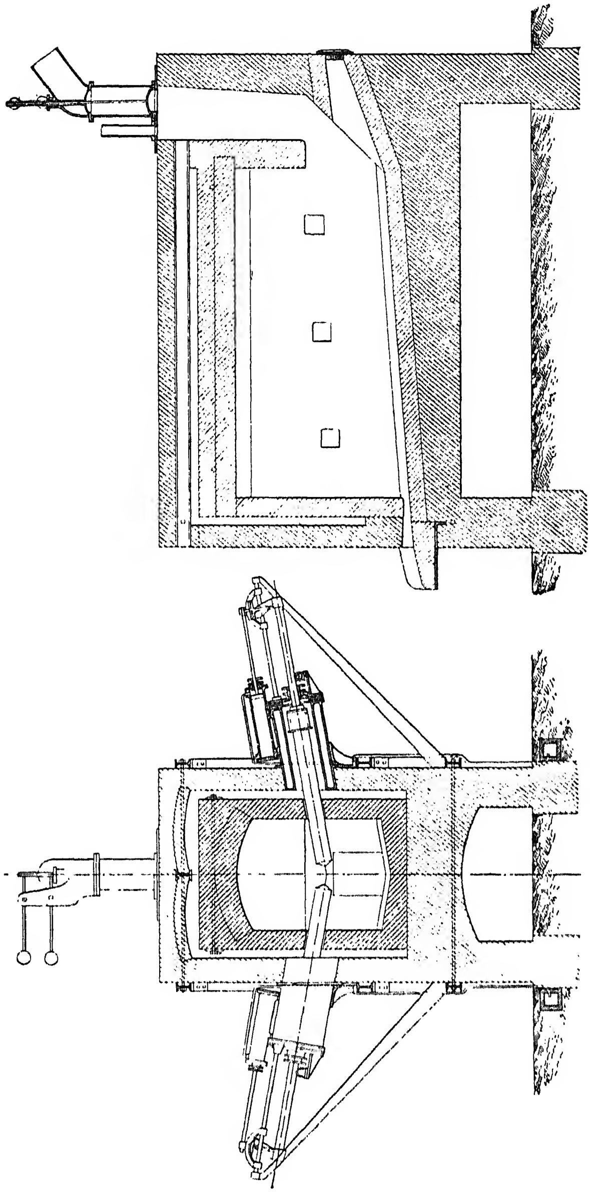


Fig. 15.—New Type of Stassano Fixed Furnace.

menting with the new type of furnace shown in Fig. 15. This furnace resembles in some respects the ordinary Martin steel refining furnace, and has a fixed hearth with two or three pairs of carbon electrodes for heating the charge of metal by arc radiation.

No details of the method of work with this furnace, or the results obtained with it, have, however, yet come into the writer's hands.

The following are figures showing the chemical composition of the iron made directly from the ore, in the rotating type of Stassano furnace :—

—	1.	2.	3.	4.	5.
Iron	99·64	99·70	99·69	99·74	99·76
Manganese ..	0·106	0·095	0·109	0·083	0·092
Silicon......	0·048	0·022	0·028	trace	trace
Sulphur	0·073	0·062	0·046	0·065	0 059
Phosphorus...	0·0055	0 024	0·013	0·0016	0·009
Carbon......	0·120	0·092	0·113	0·091	0.090

The power consumption in these runs varied between 7·00 and 4·22 E.H.P.-hours per kilogramme of iron produced, the lowest consumption being obtained in run No. 5.

In a Paper contributed to the Faraday Society in April, 1906, Major Stassano gave some figures for the work of the 200 H.P. furnace erected by his company at Turin, which are an improvement upon any yet published. When in use for refining scrap and pig iron the consumption of electric energy by this furnace varied between 1·1 and 1·3 kw. hours per kilogramme of steel or iron produced, this being equivalent to 1·5 and 1·76 E.H.P.-hours per kilogramme of iron. The yield of the furnace was stated to be 2·4 tons per day of 24 hours. The weak feature of this furnace was the wear and tear on the refractory lining; for Stassano himself estimated the cost of the renewal of these at 10 fr. per ton of metal produced.

CHAPTER VI.

MISCELLANEOUS METHODS AND FURNACES.

In Chapters II. to V. of this book, the electric furnace methods of iron and steel production that have received the most lengthy trials upon a laboratory and industrial scale of operations have been described, these being the Héroult, Keller, Kjellin and Stassano processes. In the case of two of these considerable industrial progress has been made, and the furnaces and processes may be considered to have taken a permanent place in the iron and steel industry.

The remaining furnaces and processes will be dealt with in this chapter. These have not been so long before the public, and are more or less experimental in character. They are worthy of attention, however, because some of them exhibit novel features in principle or design, and it is quite possible that one or more of these processes will prove economical and become of considerable industrial importance in the future. The furnaces and processes will be described in alphabetical order.

The Conley Furnace.—Fig. 16 is a sectional elevation of the Conley furnace. This furnace follows the blast furnace principle in design and construction. The heating and reduction of the ore are effected by contact of the crushed and well-mixed ore, lime and coke with transverse electrode plates fixed in the throat of the furnace. A central partition wall, A, is added to the usual blast-furnace design, and the electric current is conveyed to the charge of ore, lime and coke by means of the electrode plates B and D. The partially-fused

and reduced charge then falls on to the hearth of the furnace at C, where the heating and reduction is completed by the belt-shaped ring of electrode plates, E. It has been estimated that a 100 ton furnace of this type would require 5,000 H.P., and that steel ingots could be produced by it a cost of £2. 9s. 4d. per ton. The patents for this furnace were purchased by the Electric Furnace Co. of New York, and plants were designed for erection at Elizabeth Town and Massena, U.S.A.

No details of the practical development of these schemes for the utilisation of the Conley furnace have been published, and it is probable that financial difficulties have hindered its further progress.

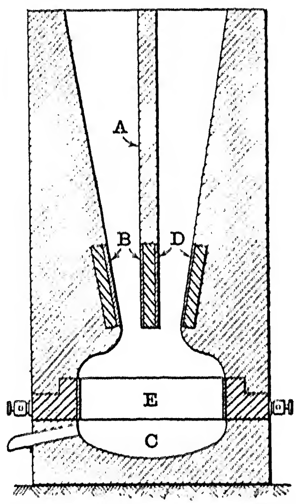


FIG. 16.—THE CONLEY FURNACE.

The Galbraith Furnace.—Fig. 17 is a sectional elevation of the Galbraith furnace, designed for smelting New Zealand iron sands. An experimental demonstration with the furnace occurred at Loughborough, England, in July, 1905. This furnace, in principle, is a resistance-heating furnace, a number of graphite resistance bars being employed in the circuit to convey the heat generated by the electric current to the mass of ore and coke. These graphite bars are called "Incandes-

cents" in the patent claims covering this furnace, and are fixed in a tower or column in such a manner that the iron-sand and coke in the powdered state falls from one to the other in its descent from the top to the bottom of the tower. In operating the furnace, a feed-box supplies a constant stream of iron-sand mixed with a pre-determined amount of coke or

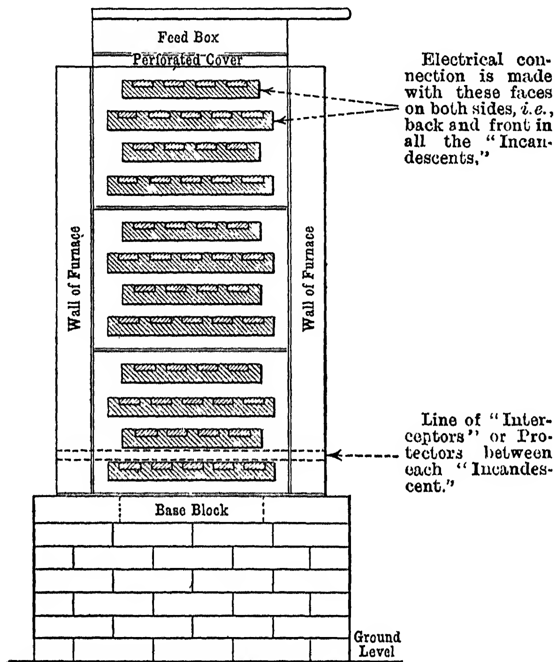


FIG. 17.—THREE-TIER EXPERIMENTAL "GALBRAITH" ELECTRIC FURNACE (NOT DRAWN TO SCALE). SECTIONAL ELEVATION SHOWING 4- AND 5-BAR "INCANDESCENTS" IN SECTION.

charcoal to the furnace, and this, it is claimed, leaves the furnace at the bottom in a stream or shower of molten metal. The demonstration of the furnace and process at Loughborough was not very successful, and the writer is unaware whether the funds required for the development of the Galbraith process in New Zealand in connection with a large water-power scheme have yet been raised.

The Gin Furnace.—M. Gin, a French electrometallurgist who assisted in the development of the aluminium and calcium carbide industries in France, has latterly devoted himself to the subject of iron and steel production, and a very large number of patents have been taken out in his name.

A company named the Société des Procédés Gin pour la Metallurgie Electrique, with a capital of 900,000fr., was formed in 1905 to take over the Gin patents relating to all branches of electro-metallurgy, and arrangements have been made for trial of the Gin iron and steel furnaces at Plettenberg in Germany.

The special feature of the earlier type of furnace was the use of narrow channels to contain the metal during the heating process, this heating being effected by the resistance method. In the furnace in which the canal was bent upon itself the narrow cross-section of the canal was not convenient for the introduction of ore or scrap, and therefore a modified form has been designed, in which the heating and refining processes take place in separate portions of the furnace. The heating occurs in the narrow channels connecting the chambers in which the refining operation is carried out. When the metal has attained the required composition a certain quantity of the finished steel is tapped, and the volume of metal withdrawn from the last chamber is replaced by an equal volume of metal heated to a high temperature from the canal leading to it. A quantity of metal equal to that withdrawn is also charged into the chamber farthest from the tap-hole. Fig. 18 gives various views of a refining furnace of this type, designed to utilise 7,200 kw. in the form of a current of 60,000 amperes at 120 volts. The yield from this furnace would be 350 tons per 24 hours.

No details have yet been published concerning the success or otherwise of the installation at Plettenberg, but M. Gin, in a Paper contributed to the Faraday Society of London, in April, 1906, admitted that one of the difficulties met with had been to find a material for the furnace base and walls sufficiently refractory and non-conducting to prevent short-circuits between the canals and chambers.

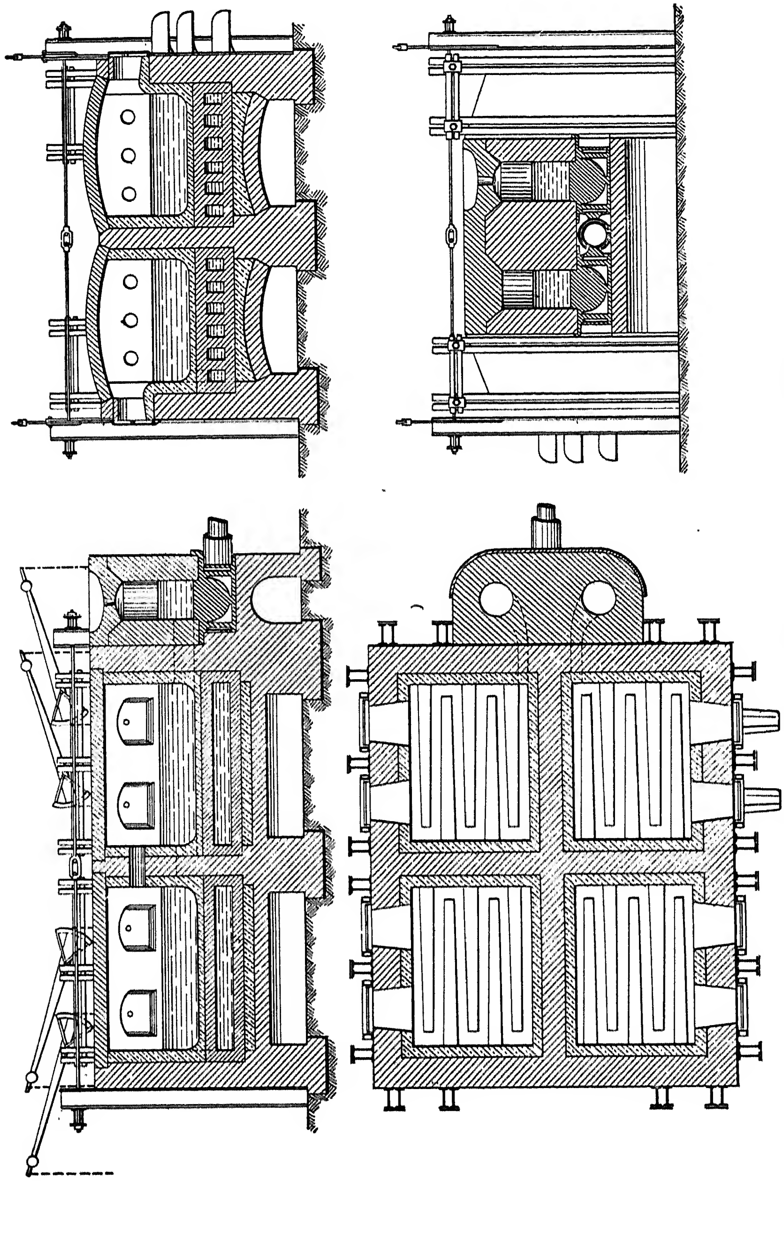


FIG. 18.—SECTIONAL ELEVATIONS AND PLAN OF GIN'S CHAMBER FURNACE.

Another type of furnace which M. Gin has designed is shown in Fig. 19. This form is called a combination furnace, and it consists of three parts: (1) a melting and oxidising crucible, (2) a deoxidising and recarburetting chamber, and (3) a final mixing chamber. The electrodes enter the furnace from above and are not shown in the figure.

The electrodes of chamber (1) are connected to one of the current terminals, and the electrodes of chambers (2) and (3) are connected in parallel to the other terminal. The current passes from the electrodes to the metal through "a layer of

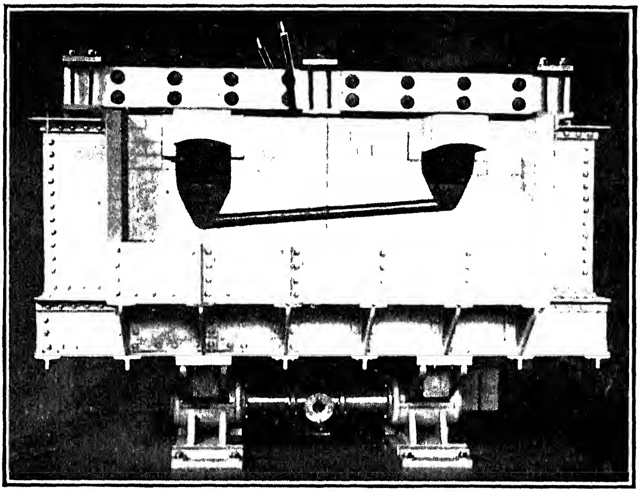


Fig. 19.—New Form of Gin Furnace. Combination Tilting Type.

scoriæ," the resistance of which causes the generation of heat, and then through the metal in the narrow connecting channels. Different slagging materials can be added to each chamber, in order to attain the composition desired in the final product. The furnace is held together by a metal case which rests on rollers, so that the furnace can be tilted for the removal of slag or metal. The channel between chambers (2) and (3) is so placed that it is uncovered at the moment the tapping begins. This prevents the metal of chamber (2) from mixing with that

of chamber (3) during the tapping operation. By tilting the furnace in the opposite direction the metal of chamber (2) is transferred to chamber (3), and the slag is always retained in chamber (1) in every position of the furnace. The transfer of metal from chamber (1) to chamber (2) is effected in a similar manner.

The writer is not aware that this furnace has yet received practical trial, but its great similarity in principle to the Héroult steel refining furnace proves that it will operate successfully under proper conditions and management. It differs in principle from the canal and chamber type of furnace, in that the resistance of the scoriæ—*i.e.*, the slag—is made use of to convey the heat of the electric current to the molten metal, whereas in the earlier designed furnaces the resistance of the metal itself was employed. This is likely to raise important questions of patent validity at some future date.* As regards the power required to produce steel in these two types of furnace no very reliable figures are available for publication. M. Gin's own estimates give a power consumption of between 640 kw.-hours and 720 kw.-hours per ton of steel, for a plant designed to produce 30,000 tons per annum. With ore at 15fr. per ton and power at 80fr. per kilowatt year, the cost then works out between 82fr. and 83fr. per ton of finished steel. In these calculations it is assumed that the iron is run into the refining furnace in the molten condition, from a blast furnace of the ordinary type.

The Canadian Commissioners were not able to see M. Gin's furnace in operation when they visited Europe, and, therefore, no independent figures are available.

The Girod Furnace.—M. Paul Girod occupies the post of electro-metallurgist to the Société Anonyme Electro-Métallurgique, who own works at Albertville and at Ugine in France, and also at Courtepin in Switzerland. This company is chiefly occupied in the manufacture of special ferro-alloys for steel

* In reply to criticisms upon this point raised at the September, 1905, Meeting of the American Electro-chemical Society, M. Gin stated that the use of the slag as a heating medium was covered by his patent of February, 1897.

makers, ferro-tungsten being their chief product; but M. Girod has also devised a special furnace for steel refining which has been submitted to trial at the Albertville works, with successful results. The furnace is shown in sectional

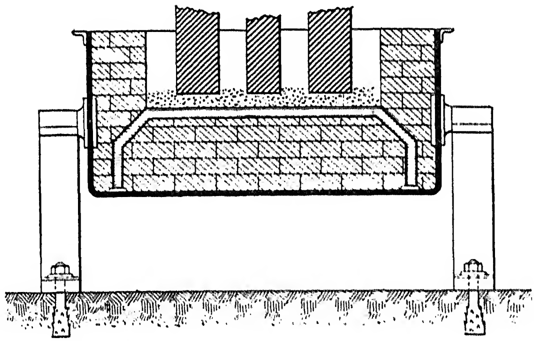


FIG. 20.—SECTIONAL ELEVATION OF GIROD'S FURNACE.

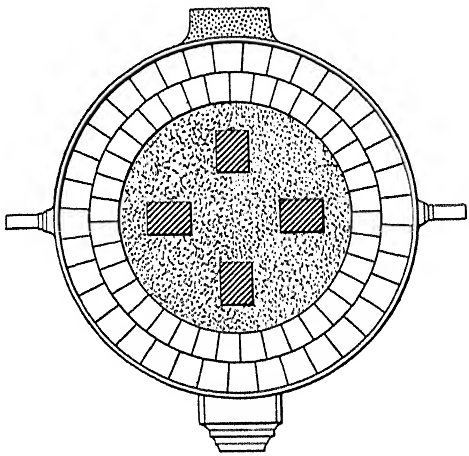


FIG. 21.—SECTIONAL PLAN OF GIROD'S FURNACE.

elevation in Fig. 20, and in sectional plan in Fig. 21. The furnace is cylindrical in shape, is mounted on trunnions, and is lined with magnesia brick. The cover is made of silica brick and through this pass several carbon electrodes, all of which

are connected to one pole of the electric supply circuit. The bottom of the furnace is formed of a number of water-cooled pieces of cast iron embedded in the brickwork. These act as the lower electrodes of the furnace, and for a furnace 2 metres in diameter, 14 of these plates are used. Each plate is in contact with the crucible part of the furnace, by means of the canals shown in section in Fig. 20, these canals being filled with soft iron in the molten state before the furnace run begins. Alternating current is used. The charge consists of scrap and cast iron in suitable proportions. The upper electrodes are suspended in the slag, which is made up from special ores, and the decarburisation of the charge is carried as far as possible, to eliminate all the impurities of the raw iron. The steel is then recarburised by adding a calculated weight of high carbon metal. A 250 kw. furnace of this type has been operated at Albertville and has produced 1 ton of steel from 1½ ton charges, in 4½ hours. The cost of running has been estimated as follows: Electric energy 1,060 kw.-hours at ¼d. £1. 2s. 1d., electrodes 10 kg. 10d., maintenance charges 6s. 8d., or £1. 9s. 7d. per ton of steel.

Girod has also patented a large number of forms of crucible furnace in which the charge is melted by resistance heating, the crucibles being embedded in a crushed mixture of carbon and silica, and a large number of crucibles being placed in one furnace. It is claimed for these furnaces that the temperature can be varied from 500°C. to 3,500°C. without difficulty, by varying the E.M.F., and that the most refractory metals and alloys can be melted in them. The furnaces are made for about 200 H.P., and work with a normal pressure of 0·25 volt. Each furnace produces about 2,000 kg. of steel per day, at a cost of 19s. 2d. per ton, with an expenditure of 1,440 kw-hours.

The Girod furnace has, however, not been applied upon an extensive scale for steel making up to the present time. The 15,000 H.P. available at the three works named above have been chiefly utilised for the production of ferro-alloys, and there has not been any special effort made to push the other application of the furnace and process.

The Harmet Furnace.—M. Harmet was connected with the Fonderies, Forges et Acieries, St. Etienne, when Héroult was developing his electro-thermic steel refining furnace, and the furnace described below is reported to be due to M. Héroult's attempt to introduce his process of steel refining at St. Etienne.

The Harmet furnace is shown in sectional elevation in Fig. 22. The general plan comprises three parts, each corresponding to one phase of the treatment of the ore and molten metal. In

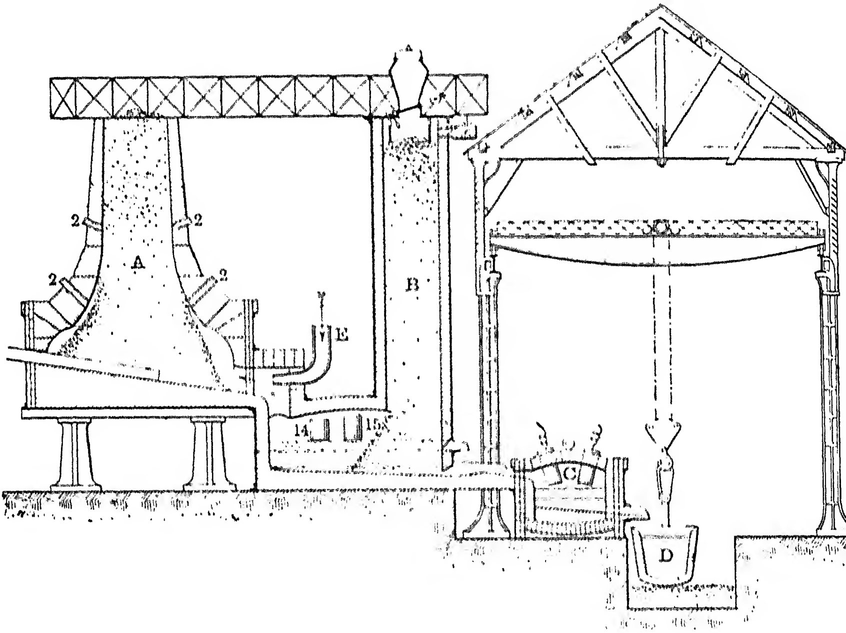


FIG. 22.—THE HARMET FURNACE.

the first shaft (A) the ores are fused, in (B) they meet with the pre-heated reducing and slagging materials from this column, and are reduced to the metallic state, while in (C) the final refining operation is carried out. The progress of the ore and metal through (A) and (B) is continuous, while (C) is tapped intermittently. The heating of the ore and other materials in A and B is effected largely by the heated gases escaping from B and C, but resistance heating is also employed,

carbon electrodes being placed at suitable points in the walls of A and B (*see* 2, 2, 2, 2, 6, 6, 14 and 15). The heating of the metal in the refining crucible is carried out by massive carbon electrodes passing through the top of the crucible, and carrying a current of electricity which passes from the one electrode through the slag and metal back to the other electrode. The complete furnace is therefore a combination of the Keller and Héroult furnaces already described, with an attempt to utilise the heat of the waste gases for the preliminary heating of the raw materials—coke, lime and ore.

M. Harmet has calculated that one ton of steel can be made in this furnace with an expenditure of between 2,500 and 3,600 E.H.P.-hours, and has estimated the cost at 29.24fr. per ton for electric power and coke alone. These estimates are based solely upon theoretical calculations, and must be accepted with some reserve.

The writer is not aware that the Harmet process and furnace are now in operation, although it is stated that trials of the furnace were carried out at St. Etienne a few years ago.

The Hiorth Furnace.—This furnace has recently been patented by F. Hiorth, of Christiania, and is somewhat similar in principle and design to the Kjellin furnace described in Chapter IV. Fig. 23 is a sectional elevation of the new design which provides for two or more furnaces being served by the one transformer coil. The iron core of the transformer is D-shaped, and is mounted as shown at B; the primary coil is indicated at S. A current of 90 amperes at 3,000 volts pressure is supplied to this coil, and is said to be transformed into a current of 3,000 amperes at 70 volts in the secondary circuit of the transformer, which in this case is formed by the mass of metal contained in the annular channel C of the furnace. An efficiency of 78 per cent., and a temperature of 2,000°C., are reported to be attained. The furnace is built as a hollow brickwork cylinder, D. The channel which contains the iron is covered by lids, L, to prevent oxidation of the metal during the refining operations. The screen R is provided to protect the coil S from the heat radiated by the walls

of the furnace. A is the spout by which the metal is tapped when ready for discharge.

There is little to distinguish the Hiorth furnace up to this point from the Kjellin type, but the provision made for rotating the electromagnet on its axis, and swinging it round into the position shown by the dotted lines, is a peculiar feature of the Hiorth design, and may be held to substantiate the claim for novelty.

By utilising this plan in the construction of transformer furnaces it is claimed that continuous operation is attained, and that the capital expenditure upon the electrical portion of the plant is reduced. It is not clear, from the drawing, how

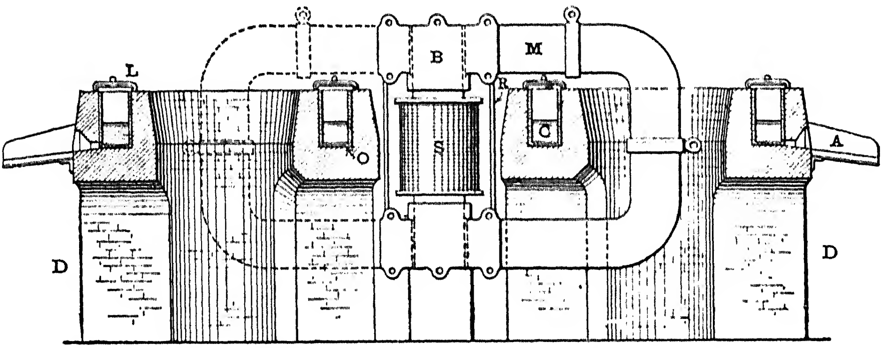


Fig. 23.—The Hiorth Furnace.

the furnace design allows for the removal of the coil from the centre by swinging round on its axis without destruction to the furnace walls, and it may be doubted whether this plan in practice would offer the advantages claimed for it by the inventor. The similarity to the Kjellin furnace is also likely to raise questions of patent priority should the Hiorth furnace ever be operated upon an industrial scale; but, so far as the writer is aware, the furnace has not yet been worked on a large scale.

The Ruthenberg Furnace.—The Ruthenberg furnace is shown in Fig. 24, a reproduction of a photograph taken from an experimental furnace erected at Lockport, N.J., in 1902, and

described by the inventor in the issue of *Electro-chemical Industry* for February, 1903.

The furnace consists of two magnetic rolls carrying an electric current, between which the ore, mixed with a calculated amount of carbon is fed. The ore is picked over to free it from gangue, and is crushed before use. The poles of the magnet are within the bronze rolls, which are driven by a small motor and worm-gearing at a speed of 4 revs. per min. The rolls carry a current of 700 amperes at 50 volts, and are water cooled. The magnetic action of the rolls holds a bridge of the crushed particles of ore and coke in the narrow gap. The electric current passes from one roll to the other through

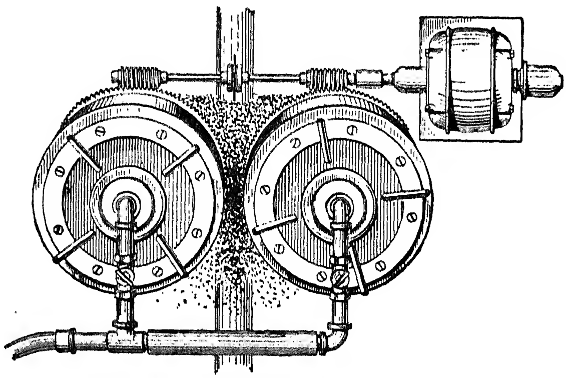


FIG. 24.—THE RUTHENBERG FURNACE.

this crushed ore and coke before the latter is carried downwards by the revolution of the rolls and dropped into the soaking pit below.

The metal produced in this way requires smelting and refining in an open-hearth steel furnace before it can be placed upon the market. If successful, therefore, the process is really one of ore agglomeration with partial reduction of the iron oxide to the metallic state.

The inventor in his original specification claimed the further reduction of the agglomerated ore in a special chamber by means of waste furnace gases, but this part of the patent does not appear to have been developed.

As regards cost, Ruthenberg stated that one ton of steel could be produced by his process with an expenditure of only 500 kw. hours, and an experimental plant was erected at the works of the Cowles Electric Smelting Co., at Lockport, N.J., in 1902, to substantiate this claim. The plant attracted much notice, and was visited by a large number of steel makers in January, 1903, but the further development of the process has not realised the inventor's hopes. In July, 1903, this experimental plant at Lockport was visited by three of the Canadian Commissioners, and their report upon it was distinctly unfavourable, as they found little reduction or agglomeration of the ore had occurred, either in the gap between the rolls or afterwards in the soaking pit. The company financing the trials has since gone into liquidation, but it is reported that further trials of the process and furnace will be made at Niagara Falls. The writer does not consider that these are likely to result in financial success, but the process is interesting on account of its novel features, and it is, therefore, worthy the study of electro-metallurgists.

CHAPTER VII.

YIELDS AND COSTS.

A very large number of figures for the yields and costs of the electric furnace methods of iron and steel production have been published during the last six years, and the practical metallurgist in search of correct information is likely to be somewhat dismayed by the mass of statistics and by the great variations which are found on reducing these figures to a common basis of comparison.

It is necessary to remember, however, that many of the figures are only estimates, and that these do not possess the value or weight of figures based upon actual trial of the processes. Again, the variations in the cost of electric power in different localities, and the different methods of working tbe electric furnace for iron and steel production, all contribute to the variations in the cost per ton of finished steel. The consumption of electric power and the total costs are, of course, highest in those cases in which the process is worked as a reduction process, and the raw materials—iron ore, lime and coke—are charged into the furnace without any preliminary heating. On the other hand, the consumption of electric power and total costs are lowest when the process is conducted solely as a refining process, and molten pig iron from the blast furnace is used as raw material in the electric furnace. Between these two extremes there are many intermediate values, due to modifications in the methods of conducting the process and in furnace design. In the following pages an attempt will be made to discriminate between figures of weight and those of little value. Comparisons between yields and costs for different furnaces and processes will only be made

when the conditions under which the trials were carried out are similar in character and a fair comparison is possible.

The furnaces and processes will be dealt with in the order followed in Chapters II. to VI., the authority for the figures being given in brackets after the same:—

I.—Héroult Furnace and Process.

(a) Steel Production from Pig Iron and Scrap charged cold into crucible type of Furnace with Carbon Electrodes.

Trial No. 1. 882 kw.-hours per metric ton of 2,204 lb. (Goldschmidt.)

Trial No. 2.—1,000 kw.-hour per short ton of 2,000 lb. (Canadian Commissioners.)

Trial No. 3.—1,000 kw.-hours per short ton. (Canadian Commissioners.)

Trial No. 4.—653 kw.-hours per short ton. (Canadian Commissioners.)

The quality of steel produced in No. 1 trial was not stated; in No. 2 a dead soft steel was produced; in No. 3 a hard tool steel; and in No. 4 trial a steel adapted for structural purposes.

(b) Steel Production from Scrap melted and over-oxidised in an Open Hearth Furnace.

Trial No. 1.—360 kw.-hours per metric ton of 2,204 lb. (Eichoff.)

This trial was made at the Remschied works in Germany; the quality of steel produced was not stated.

(c) Pig Iron Production.

Trial No. 1.—3,080 kw.-hours per short ton. (Canadian Commissioners.)

Trial No. 2.—2,306 kw.-hours per short ton. (Haanel.)

Trial No. 3.—2,342 kw.-hours per short ton. (Haanel.)

The iron produced in No. 1 trial was a close-grained grey pig, in No. 2 a grey iron, high in carbon and silicon, and in No. 3 trial a similar iron containing between 3 and 4 per cent. of nickel.

A large number of other figures have been published for the Héroult process, but these are mere estimates and lack the weight of the above results. They are therefore omitted from this comparison. Taking the mean of the above values for each product we have the following figures for the Héroult process and furnace:—

1. Steel from cold pig and scrap.—864 kw.-hours per 2,000 lb.
2. Steel from molten open-hearth steel.—329 kw.-hours per 2,000 lb.
3. Grey pig-iron from ore.—2,693 kw.-hours per 2,000 lb.
4. Ferro-nickel pig from ore.—2,342 kw.-hours per 2,000 lb.

II.—THE KELLER FURNACE AND PROCESS.

(a) Steel Production from Ores and Slagging Materials charged Cold.

Trial No. 1.—2,800 kw.-hours per metric ton. (Goldschmidt.)

(b) Steel Production from Pig Iron charged Cold.

Trial No. 1.—730 kw.-hours per short ton. (Canadian Commissioners.)

(c) Pig Iron from Ores and Slagging Materials charged Cold.

Trial No. 1.—3,110 kw.-hours per short ton. (Canadian Commissioners.)
Trial No. 2.—1,475 kw.-hours per short ton. (Canadian Commissioners.)

In No. 1 trial a grey pig containing a considerable percentage of silicon and manganese was produced. In No. 2 trial a pig suitable for steel manufacture by either the acid Bessemer or Siemens process. The great difference in energy consumption was ascribed to a change of furnace and to inaccurate estimation of the weight of unused ore.

(d) Steel from molten Pig Iron.

Trial No. 1.—691 kw.-hours per metric ton. (Neumann.)

Arranging these figures as before, we have the following yields for the Keller furnace and process :—

1. Steel from cold pig and scrap.—730 kw.-hours per 2,000 lb.
2. Steel from molten pig.—631 kw.-hours per 2,000 lb.
3. Grey pig iron from ore and raw materials charged cold.—2,292 kw.-hours per 2,000 lb.
4. Steel from ore and raw materials charged cold.—2,800 kw.-hours per 2,000 lb.

III.—THE KJELLIN FURNACE AND PROCESS.

Steel from Pig Iron and Scrap charged Cold.

Trial No. 1.—970 kw.-hours per metric ton. (Goldschmidt.)
Trial No. 2.—966 kw.-hours per metric ton. (Neumann.)
Trial No. 3.—757 kw.-hours per short ton of 2,000 lb. (Canadian Commissioners.)
Trial No. 4.—947 kw.-hours per short ton of 2,000 lb. (Canadian Commissioners.)

No details are available relating to the character of the steel made in trials Nos. 1 and 2. Sample No. 3 contained 1·08 per cent. carbon, 0·194 per cent. of silicon and 0·24 per cent. of manganese, while No. 4 contained 0·417 per cent. of carbon, 0·145 per cent. of silicon and 0·110 per cent. of manganese. Owing to the lower temperature attained, as compared with the Héroult process, the purity of the product depends largely upon the purity of the raw materials charged, and there is no

burning out of the impurities as in the latter process. The Kjellin furnace and process are not adapted for the production of pig iron or steel direct from the ores. No trials have yet been made using molten pig for charging in place of cold materials.

Taking the average of the figures given above, we have the following yield:—

1. Steel from cold pig and scrap.—866 kw.-hours per ton of 2,000 lb.

IV.—The Stassano Furnace and Process.

(a) Steel from Ore, Coke and Lime charged Cold.

Trial No. 1.—2,866 kw.-hours per metric ton. (Goldschmidt.)
Trial No. 2.—3,155 kw.-hours per metric ton. (Neumann.)
Trial No. 3.—3,230 kw.-hours per metric ton. (Stassano.)

No details of the character of the iron produced in these trials are available. The purity of the product depends largely upon the purity of the materials used.

(b) Steel from Scrap charged Cold.

Trial No. 1.—1,360 kw.-hours per metric ton. (Stassano.)
Trial No. 2.—1,200 kw.-hours per metric ton. (Stassano.)

No figures relating to the character of the steels produced in these trials are available. Owing to the high temperature of the arc and the closed furnace the product is similar to that obtained in the Héroult furnace.

Taking the averages of the above figures we have the following:—

1. Steel from ore, coke and lime charged cold.—2,804 kw.-hours per ton of 2,000 lb.
2. Steel from scrap charged cold.—1,164 kw.-hours per ton of 2,000 lb.

V.—The Gin Furnace and Process.

So far as the writer is aware, no practical results based on trials of this furnace and process have been published, and the figures given in the somewhat voluminous papers and reports prepared by M. Gin are mere estimates based on study of theoretical data. For this reason the figures for the Gin furnace and process are less important than those previously dealt with, and only one estimate will be given—namely, for

Steel from molten pig iron.—680 kw.-hours per metric ton, equivalent to 618 kw.-hours per ton of 2,000 lb.

VI.—The Girod Furnace and Process.

This furnace and process have received actual trial, and the following figures are based upon the result:—

Steel from Scrap charged Cold.

No. 1 trial.—1,060 kw.-hours per metric ton.
No. 2 trial.—1,440 kw.-hours per metric ton.
Mean.—1,136 kw.-hours per ton of 2,000 lb.

No details of the character of the steel produced in these trials are available.

VII.—The Harmet Furnace and Process.

(*a*) *Steel from ore in combined reduction and refining type of furnace, the ore and other raw materials being heated by waste heat from the later stages of the process.*

No. 1 estimate.—1,837 kw.-hours per metric ton.
No. 2 estimate.—2,646 kw.-hours per metric ton.
Mean.—2,242 kw.-hours. per metric ton, equivalent to 2,038 kw.-hours per ton of 2,000 lb.

Combining the results set out above for purposes of comparison, we have the following:—

—	I. Héroult.	II. Keller.	III. Kjellin.	IV. Stassano.	V. Gin.	VI. Girod.	VII. Harmet.
Steel from scrap and pig (cold)..	864	730	866	1,161	..	1,136	..
Do. (hot)	329	631	..	..	618	..	..
Pig iron from ore, coke and lime (cold).	2,693	2,292	..	..	..	..	..
Steel from ore, coke and lime (cold).	..	2,800	..	2,804	..	..	2,038
Nickel pig from ore ..	2,342	..	..	..	..	..	..

All results are given in kilowatt-hours per ton of 2,000 lb.

These figures show that, as regards the manufacture of steel from scrap and pig iron, charged cold, the Héroult, Kjellin and Keller furnaces all yield results in the neighbourhood of 800 kw.-hours, while the Stassano and Girod furnaces have an energy consumption 50 per cent. higher. The Héroult and Keller furnaces and processes are able to deal with more impure

materials than the Kjellin furnaces, since the use of the electric arc as a source of heat produces a much higher temperature than induction heating, and this enables all the impurities of the raw iron to be oxidised and removed in the slags. On the other hand, the Kjellin furnace and process gain by the absence of carbon electrodes and by the generation of heat entirely within the material contained in the furnace. The costs of operating and of maintenance are thus greatly reduced, and this saving balances the higher expenditure upon raw materials. It is, however, probable that each type of furnace will be found adapted for the production of steels of special quality, and that both the arc type of crucible furnace (represented by the Héroult and Keller furnaces) and the induction type (represented by the Kjellin and Hiorth furnaces) will attain a permanent position in the steel industry of the future.

The figures given for the energy consumption when the steel and scrap are charged into the furnace in the molten condition are hardly comparable, since it is evident that the Keller and Gin trials were made under conditions dissimilar from those obtaining in the Héroult trials. It has been calculated by Neumann that 433 kw.-hours are necessary to raise 1 ton of iron to the molten state, and it is therefore certain that when the iron is charged in this condition into the electric refining furnace, a reduced power consumption of 400 kw.-hours per ton of steel produced should be obtained. The figure given by Eichoff for the working of the Héroult process at Remschied—namely, 320 kw.-hours—may possibly be too low, but working under these conditions a power consumption of only 410 kw.-hours per ton of steel produced should be attainable.

This reduction of 50 per cent. in the electric power required is so important that it is evident the development of electric furnace work in the iron and steel industry in the near future must proceed along these lines. At Remschied, in Germany, and at Syracuse, in America, a Wellman open-hearth furnace is being employed for the preliminary heating of the metal, in order to obtain an over-oxidised product as raw material for the electric refining furnace. The next step

will be to dispense with this intermediate furnace process, and to transfer the pig iron, as it runs in the molten condition from the blast furnace, directly to the electric crucible furnace—for the final refining operation. The present writer prophesied this development some years ago, and he still expects to see it realised.

The figures for the power consumption when the electric furnace is employed to reduce the ores and to produce pig iron or steel in one operation are less hopeful than those given above. For pig iron production the power consumption appears to lie between 2,300 kw.-hours and 2,700 kw.-hours, these figures being for the materials charged cold, and a reduction of between 300 kw. and 500 kw. being possible, if the raw materials are partially melted before bringing under the heating action of the electric current. It is improbable, however, that the electric power required for producing iron or steel from the ores, even with preliminary heating of the ore and other raw materials, can be reduced below 2,000 kw.-hours per short ton of metal. It will be shown in the final section of this chapter that power would have to be obtained at a very low cost to render competition with the ordinary blast furnace procedure practicable even on this basis.

The use of the electric furnace for iron ore reduction is, therefore, in the writer's opinion, not likely to undergo any industrial development at present, excepting under very special conditions. In some cases it may prove possible, by use of electric furnace methods, to manufacture iron or its alloys out of ore deposits which are otherwise unworkable, and in these cases the new methods of heating will, of course, find early application. The attempts to smelt New Zealand iron sand and the titaniferous ores of America are examples of this use. The trials of the Héroult furnace and process at Sault Sainte Marie in Canada are reported to have led to a similar result, for the plant which is to be erected as the outcome of these trials is to be used for the smelting of nickel-iron ores, and not for the production of ordinary pig-iron.

In countries like Norway and Switzerland, with abundance of water power that can be developed at very low cost, it is

possible, again, that a native iron-smelting industry might be established, if iron ore and lime are found in the locality of the water-power. But here, again, special conditions will be required to render the industry a financial success, and it is unlikely that the iron will be able to compete in price with the product of the ordinary blast furnace in the open market. Until the coalfields of Europe and America are more nearly exhausted than at present, the electric furnace methods of iron smelting will therefore, in the writer's opinion, undergo little development, and it is in the production of special steels and alloys in the electric refining furnace that the greatest progress is likely to occur within the next few years. That an electric iron smelting industry will some day be established the writer does not deny—but the conditions at the present time are not favourable to its early development—and they are hardly likely to be so for another 20 or 50 years.

Costs.

The figures for the costs of working the various electric furnaces and processes for iron and steel production are less reliable than those given in the preceding section of this article, since in practically all cases they are based on estimates rather than upon figures obtained from actual work.

The cost of ore, lime, coke and fluxes, and the cost of electric power can, of course, be obtained with exactitude for the various processes and localities, but such important items as electrodes, depreciation, repairs, interest on capital and management are largely unknown charges, and may be greater in the aggregate than is yet realised. The costs of electrodes and repairs are, of course, highest in the furnaces and processes using arc heating, and these processes are heavily handicapped by the expenditure upon these two items of running costs. The furnaces and processes using the induction methods of heating have a striking advantage here, since the outlay upon electrodes is nil, and the wear and tear of the furnace structure is small.

In the statement given below, the costs of production as given by the various furnace designers, and by others who

have reported upon their working, are set down in the order followed in the first section of this chapter, but no attempt is made to institute comparisons between the various processes on the basis of these costs, since the variables are too numerous and conflicting. It is for this reason that an opinion upon the future of these electric iron and steel processes has been given at the end of the previous section, since the figures for power consumption are mostly based on actual trials, and possess a value lacking in those which are given below :—

I.—Héroult Furnace and Process.

(*a*) *Steel from Scrap.*—£2. 16s. per ton of 2,000 lb. exclusive of cost of scrap.

(Electric power at £2 per electrical horse-power-year.)

(*b*) *Pig Iron from Ores.*—£2 per ton.

(Ore at 5s. per ton.)

II.—Keller Furnace and Process.

(*a*) *Steel from Ores.* £4 per ton of 2,000 lb.

(*b*) *Pig Iron from Ores.* £2. 8s. per ton of 2,000 lb.

(Electric power at £2 per electrical horse-power-year and ore at 6s. per ton.)

III.—The Kjellin Furnace and Process.

Steel from Scrap.—£6. 16s. per ton of 2,000 lb.

(Electric power at £2 per electrical horse-power-year.)

IV.—The Stassano Furnace and Process.

Pig iron from ore, £3. 15s. 3d. per ton of 1,000 kg. (electric power at £1. 16s. per electrical horse-power-year and ore at 14s. 5d. per ton).

V.—The Gin Furnace and Process.

Steel from molten pig, £3. 4s. per ton of 1,000 kg. (electric power at £2. 8s. per electrical horse-power-year and ore at 12s. per ton).

VI.—The Girod Furnace and Process.

Steel from scrap, £1. 3s. 3d. per ton of 1,000 kg.

VII.—The Conley Furnace and Process.

Steel from ore, £2. 7s. 3d. per ton.

VIII.—The Harmet Furnace and Process.

Steel from ore, £1. 2s. 5d. per ton.

The above figures show such wide variations that, even as estimates, they are misleading and unsatisfactory.

In attempting to form an opinion as to the comparative cost of working the electric iron and steel processes it is therefore

better to rely upon the figures for the power consumption, given in the first section of this chapter. Taking the electrical horse-power year at £2 and the average power consumptions in Table I. we have the following costs :—

1. Steel from molten scrap, 2s. 6d. (400 kw.-hours).
2. Steel from cold scrap and pig, 5s. (800 kw.-hours).
3. Pig iron from ore, coke and lime, charged cold, 15s. 6d. (2,500 kw.-hours).
4. Pig iron from ore, coke and lime, charged hot, 12s. 5d. (2,000 kw.-hours).

In the manufacture of best crucible steel, however, it is customary to assume that between $2\frac{1}{2}$ and 3 tons of coke are consumed per ton of steel produced. At the present market price of coke (17s.) the advantage is, therefore, on the side of the electric refining furnace.

As regards the electric smelting processes, it is necessary to remember that coke is still required to reduce the oxide of the iron ore to the metallic state, and that the only fuel saved is that used in the blast furnace for heating purposes. In the best modern smelting practice only 16 cwt. of coke are required per ton of pig iron produced, and of this total 6·5 cwt. are required to reduce the ore. The saving in coke by the electric furnace method of smelting cannot, therefore, exceed 9·5 cwt., or at the present price of coke 8s. 0d.

These considerations show that the prospects for the electric refining processes are much brighter than those for the electric smelting processes, since the saving of coke in the latter is too small to balance the large expenditure upon electric power. The horse-power-year would, in fact, have to be supplied at the extraordinarily low cost of £1 in order to compete with the modern blast furnace, and the localities where it can be produced at this figure are certainly few in number. For the present, therefore, the application of the electric furnace in the iron and steel industries is likely to be restricted as a general rule to the refining processes, by which pig and scrap steel are converted into higher-priced products. In these branches it is likely to be very widely employed, and to have a most important effect upon the future development of the whole iron and steel industry.

APPENDIX.

LIST OF BRITISH AND AMERICAN PATENTS.

Héroult's Furnace and Process.

British Patents.

No. 16,293 1900
No. 14,486 1901
No. 11,576 1901
No. 11,643 1901
No. 3,912 1902
No. 6,950 1902
No. 7,027 1903

U.S.A. Patents.

No. 707,776 1902
No. 721,703 1903
No. 733,010 1903

Canadian Patents.

No. 78,160 1902
No. 79,716 1903
No. 83,762 1903
No. 84,615 1903

Keller's Furnace and Process.

British Patents.

No. 22,584 1900
No. 24,234 1901
No. 24,235 1901
No. 15,271 1902
No. 3,790 1904

U.S.A. Patents.

No. 688,861 1900
No. 754,656 1902

Canadian Patent.

No. 74,882 1902

Kjellin's Furnace and Process.

British Patents.

No. 18,921 1900
No. 14,214 1905
No. 21,416 1906
No. 22,312 1906

U.S.A. Patent.

No. 682,088 1901

Canadian Patent.

No. 73,701 1901

Stassano's Furnace and Process.

British Patents.

No. 11,604 1898
No. 8,288 1902

U.S.A. and Canadian Patents.

Applied for, but not granted at date of list.

APPENDIX.

THE COLBY FURNACE AND PROCESS.

The Colby furnace is of the inductive type and is patented in the U.S.A. in the name of Mr. Edward A. Colby. It has been tried experimentally in America at the works of Messrs. Henry Disston & Sons, at Tacony, near Philadelphia. These trials are said to have resulted satisfactorily, and the installation of a large electric furnace plant is now being considered by this firm. The original furnace used at the Tacony works was manufactured by the Induction Furnace Co., of America, and was of 131 kw. capacity. The primary consisted of 28 turns of copper tube $\frac{3}{8}$ in. inside and $\frac{5}{8}$ in. outside diameter, cooled by internal water circulation. A maximum current of 540 amperes at 240 volts could be employed with a frequency of 60.

The annular crucible, the contents of which formed the secondary, was $14\frac{7}{8}$ in. inside diameter and $24\frac{1}{4}$ in. outside diameter, by 8 in. in height. The trough was $6\frac{3}{8}$ in. deep and had a working capacity of 190 lbs.

The maximum current available for the crucible was 15,148 amperes at 8·57 volts.

The method of working this furnace was similar to that used for the Kjellin Furnace (see p. 29).

Ingots of 90 lb. were poured every hour and fresh materials were then added to the 100 lbs. of molten metal left in the furnace. Working under these conditions, from 27·5 to 37·5 kw.-hours were used per 100 lb. of ingot metal, and the maximum power utilised was 40 kw.

The fusion of the added metal was stated to be completed in 30 minutes, and the refining operation required a similar time.

The ingot metal was stated to be dense and homogeneous, but no chemical or physical tests are published in the report from which these details are taken.*

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* "Electro-Chemical Industry," June, 1907.